Transmission & Distribution Interface 2.0 (TDI 2.0)

SDRC 9.1 – Technical High Level Design

July 2017

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References

Number	Document Name	Author
Reference [1]	DER Operating Characteristics	A. Ahmadi, C. Escudero, B. Stojkovska, M. Horley, J. Horne
Reference [2]	MPE Voltage Report	Moeller and Poeller, Power system dynamic studies for TDI 2.0 Project
Reference [3]	Transmission and Distribution Interface 2.0 requirements specification Confidential	T. Manandhar, C. Escudero
Reference [4]	Security and Quality of Supply Standard (SQSS)	National Grid

Definition of Terms

Term	Definition
AC	Alternating Current
ANM	Active Network Management
ANN	Artificial Neural Networks
AVC	Automatic Voltage control
BCV	Business Continuous Volume
CIM	Common Information Model
CPU	Central Processing Unit
DC	Direct Current
DER	Distributed Energy Resources
DERM	Distributed Energy Resources Management
DERMS	Distributed Energy Resources Management System
DG	Distributed Generation
DMS	Distribution Management System
DMZ	De–militarized Zone
DNO	Distribution Network Operator
DR	Disaster Recovery
DSO	Distribution System Operator
EMS	Energy Management System
ENA	Energy Network Association
ENCC	Electricity National Control Centre
FC	Fibre Cards
FEP	Front End Processors
FTP	File Transfer Protocol
GB	Great Britain
GDPR	General Data Protection Regulation
GE	General Electric
GIS	Geographic Information System
GSP	Grid Supply Point
GW	GigaWatt
HTTP	Hypertext Transfer Protocol
HTTPS	Secured Hypertext Transfer Protocol

Term	Definition
ICT	Information Communication Technology
ICCP	Inter–Control Centre Communications Protocol
IEC	International Electrotechnical Commission
IP	Internet Protocol
IPS	Secure Internet Protocol
ISO	International Standards Organisation
IT	Information Technology
KASM	Kent Active System Management
MVAr	Mega Volt Ampere Reactive
MW	Mega Watt
NAP	Network Access Planning
NG	National Grid
NMS	Network Management System
OPF	Optimal Power Flow
OS	Operating System
P	Active Power in MegaWatts
PACE	Police and Criminal Evidence Act
PC	Personal Computer
PDU	Power Distribution Unit
PED	Personal Electronic Devices
PF	Power Factor
PKI	Performance Key Indicators
POC	Point Of Connection
Q	Reactive Power in MegaVars
RAID	Redundant Array of Independent Disks
RDP	Regional Development Programmes
RPO	Recovery Point Objectives
RTO	Recovery Time Objectives
RTU	Remote Terminal Unit
SAN	Storage Area Network
SCADA	Supervisory Control and Data Acquisition
SCP	Secure Copy Protocol
SDRC	Successful Delivery Reward Criterion

Term	Definition
SFTP	Secure File Transfer Protocol
SGAM	Smart Grid Architecture Model
SO	System Operator
SOC	Security Operations Centre
SQSS	System Security and Quality of Supply Standard
SSH	Secure Shell
STOR	Short Time Operating Reserve
SVC	Static Var compensator
STATCOM	Static Synchronous Compensator
TDI	Transmission and Distribution Interface
TNCC	Transmission Network Control Centre
UK	United Kingdom
UKPN	UK Power Networks
VARs	Volt Ampere Reactive
VLAN	Virtual LAN
VM	Virtual Machine
WAN	Wide Area Network

1. Executive Summary

The Transmission and Distribution Interface 2.0 (TDI 2.0) project, now known as Power Potential, is a world-first trial to maximise network capacity to connect more renewable energy and storage technology in the South-East region. By working jointly together, UK Power Networks and National Grid aim to open up new markets for distributed energy resources and generate additional capacity by alleviating transmission and distribution constraints. The outcome will be more renewable energy connected to the network and savings for our customers.

The project will be trialled on the South East coast, where the volume of low carbon energy connected in recent years has led to constraints on the national transmission system. The constraints National Grid face can be summarised as:

- High voltage in periods of low demand;
- Low voltage under certain fault conditions; and
- Thermal constraints during the outage season.

These constraints have led to the following challenges in the area:

- Fewer low carbon technologies can connect to the network;
- A high risk of operational issues in the network which could affect customers; and
- A high costs of managing transmission constraints.

Distributed energy resources have the potential to provide the reactive power that is needed to provide voltage support on the South Coast. This project seeks to give National Grid access to energy resources connected to UK Power Networks in the region to provide it with additional tools to manage these voltage transmission constraints. It will also open up new revenue streams for distributed energy resources by opening up a new market for them.

The TDI 2.0 project will include the creation of a regional reactive power market which will be the first of its kind in Great Britain. It will help to defer network reinforcement needs in the transmission system, ultimately saving customers money by using our existing infrastructure more efficiently.

TDI 2.0 is expected to deliver:

- 3,720 MW of additional generation in the area by 2050
- Savings of £412m for GB consumers by 2050

1.1 TDI 2.0 project approach

The TDI 2.0 project is structured into the following key deliverables:

- A commercial framework using market forces to create new services provided from DER to National Grid via UK Power Networks.
- A market solution known as Distributed Energy Resources Management System (DERMS) to support technical and commercial optimisation and dispatch.

In high level, the DERMS solution is envisaged to work as follows:

- Gather commercial availability, capability and costs from each DER.
- Run power flows assessments to calculate possible availability of each service at the grid supply point and present that information to National Grid.

- Instruct each DER to change their set–point as required and monitor their response on the day power is required by National Grid.

1.2 Report Structure

This report (representing the project SDRC 9.1) focuses on the high level design of the project and summarises the desired functionality as well as some of the design options considered to achieve it. The key evidence against report sections is summarised in Table 1 and it describes the high level architecture, main commercial framework considerations and a review of high level business processes required to operate the solution.

1.2.1 Functional high level specification – services definition

In order to design the architecture of the project, it is first required to identify what are the key functional requirements that the project needs so that it is able to deliver the aforementioned benefits. The services provided by the distributed energy resources in the context of this project are:

- Dynamic Voltage Service (for low and high voltage conditions); and
- MW re–dispatch (for thermal constraints).

The use cases also identified (and summarised in Section 3) the main DERMS required functionalities as:

- Forecasting;
- Optimal Power Flow; and
- Control and Dispatch.

1.2.2 Technical high level design – architecture design

Sections 4, 5 and 6 summarise the high level design of the project required to meet the services description.

Section 4 reviews the current Information and Communication Technology (ICT) available design options to achieve the desired service provision. The section sets out a gap analysis on the available options and which ones would be suitable to the project at this stage.

Section 5 presents the power systems options to achieve the desired dispatch and control of the services. It summarises options regarding Forecasting, Optimal Power Flow functionalities, Contingency Analysis and Power flow. The power system options together with the ICT options form the basis the basis of how DERMS will integrate to UK Power Networks’ existing systems and interfaces.

Section 6 provides a high level overview of the architecture design to date which will be finalised once the DERMS vendor is contracted. This section, which is complemented in Appendix F, provides more details on key architectural elements such as interfaces, components and security.

1.2.3 Commercial considerations

One of the project’s main goals is to provide a route to market for distributed energy resources to provide more ancillary services. Section 7 focuses on the commercial framework to make this happen, outlining the work done so far and the roles and responsibilities of everyone involved.

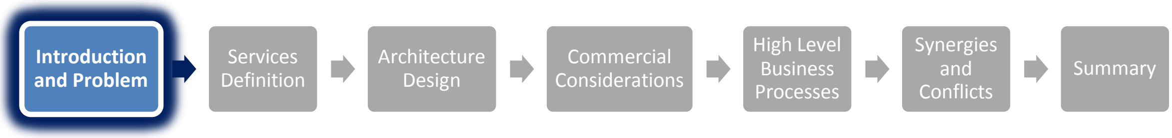
1.2.4 High level business processes

This innovative market arrangement where DER will provide services to National Grid coordinated by UK Power Networks will have significant impacts on business processes in both companies. At this stage, the focus of Section 8 is to identify what are the high level (internal) business processes required to operate the solution.

1.2.5 Review of anticipated synergies and conflicts

In section 9 of the report, a review of the anticipated synergies and conflicts identified is presented. Synergies highlighted include the Regional Development Programmes work between National Grid and UK Power Networks which seeks to find short term solutions to operational challenges in the same network area as TDI 2.0. Another synergy is the Kent Active System Management (KASM) project which has provided IT functionalities which will be used in the TDI 2.0 project.

2. Introduction



2.1 Background and project objectives

2.1.1 Context and Challenge

The South East of England has seen a significant growth in DER connections in the distribution network due to the region's geographical position and excellent solar and wind resources.

The South East Coast transmission network runs through the South of England and interfaces with UK Power Networks' distribution system at four GSPs: Bolney, Ninfield, Sellindge and Canterbury, which are located in Sussex and Kent.

Apart from the growth in DER, the South East network is influenced by the presence of two interconnectors with Continental Europe, as well as plans for two more in the years to come.

The South East network includes 2GW of peak demand and 5.5GW of large generation including wind farms, nuclear power stations and a combined cycle gas–fired power plant. Future interconnection and generation projects include:

- Rampion wind farm, comprising 400 MW connecting at Bolney GSP;
- NEMO, a 1GW interconnector to Belgium, connecting in the Sellindge GSP area; and
- ELECLINK, which will interconnect a further 1GW to France in Sellindge GSP area.

As a result of the growing levels of intermittent renewable generation, National Grid is facing increasing operational challenges managing the voltage and thermal limitations for certain network conditions, while still being able to transfer energy to the country's load centres. The constraints include:

- Dynamic voltage stability: requiring reactive power delivery at short notice;
- High voltage: managing the voltage on the network during low load periods; and
- Thermal capacity: potentially leading to generation curtailment during the summer maintenance season.

These constraints are most prominent when a fault occurs on the route between Canterbury and Kemsley, which leaves only one long westerly route to deliver the South East's green energy to in London.

If such a fault occurs the consequences can be very serious for the system. The line remaining after the fault will be required to transfer a significant amount of power. This double circuit can be characterised as a long radial line, and its electrical characteristics will lead to a rapid voltage drop across the network seconds after the fault.

If the voltage drop is not contained in time, this could lead to voltage collapse and, ultimately, a 'blackout' of the associated network. Even if a full collapse is averted, a dramatic deviation of the transmission voltage away from statutory limits can cause problems. Domestic appliances, building controls, elevators, air conditioning, and small generators, for example, might fail or trip, even though they are connected at a lower voltage on the distribution network[1].

These upstream constraints lead to the following regional challenges:

- Fewer low carbon technologies can connect in the area;
- High risk of operational issues and their consequences; and
- High costs of managing transmission constraints.

2.1.2 Our approach

Reactive compensation is needed in order to provide voltage support in the area. DER connected to the distribution network have the potential to provide reactive and active power services to the system.

TDI 2.0 seeks to give National Grid access to resources connected in UK Power Networks South East network to provide it with additional tools for managing voltage transmission constraints. To achieve this, it will develop technical and commercial solutions to maximise the use of DER to manage transmission voltage and thermal constraints. The GSPs considered in this project are Canterbury, Sellindge, Ninfield and Bolney.

The project will use a control software installed in UK Power Networks' control room which enables DER to offer dynamic reactive power services to National Grid and offer flexibility for MW re–dispatch to the SO to manage transmission constraints. The services offered by DER to the system will be coordinated by UK Power Networks as technical coordinator and is a step towards transitioning from a Distribution Network Operator to a Distribution System Operator and National Grid's future role of the System Operator.

It is estimated that TDI 2.0 will be able to create financial benefits for consumers by achieving cumulative savings in the area from £1m by 2020 to £29m by 2050 as a result of deferred investment in the transmission network. It will also create additional network capacity to enable UK Power Networks to connect a further 3,720 MW of distributed generation in the area by 2050.

2.1.3 Project timeline

The project will be delivered in the following phases:

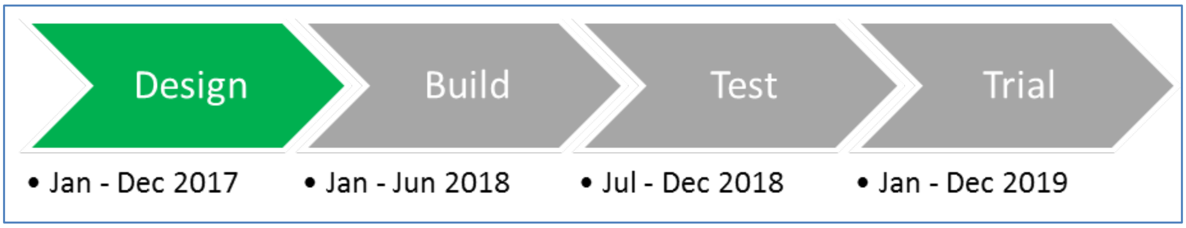


Figure 1 – Project timeline

2.2 Purpose of document

The purpose of the document is to describe the project's high level design. The document will present the main project functionality in terms of the TDI 2.0 services. The high level architecture and design options considered to deliver the functionality will be presented. The document also provides an overview of the high level commercial framework considerations as well as the high level business

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[1] TDI 2.0 Project proposal: https://www.ofgem.gov.uk/system/files/docs/2016/11/final_submission_tdi_2.0.pdf

processes required to operate the solution. Finally, an overview of anticipated synergies and conflicts at this stage is presented.

Key evidence criteria of SDRC 9.1 is presented in Table 1

Criteria	Evidence	Section
Technical High Level Design – the high level design of the technical solution and high level business processes which will operate the solution.	• Alternative design options considered and selection criteria	Sections 4 and 5
	• High level design specification	Sections 6, 7 and Appendix F
	• Functional design document	Section 3
	• High level business processes	Section 8 and Appendix E
	• Review of anticipated synergies and conflicts	Section 9

Table 1 – Key evidence criteria of SDRC 9.1 and corresponding sections of the document

3. Functional Design High Level Specification – Services Definitions

Introduction and Problem
Services Definition
Architecture Design
Commercial Considerations
High Level Business Processes
Synergies and Conflicts
Summary

3.1 Purpose

This section presents the considerations taken to design the TDI 2.0 services. It presents the concept of wind farm voltage control and how the TDI 2.0 services could work to have a similar performance. It also presents the high level description of the functionality for the TDI 2.0 services: Dynamic Voltage Control (for Low Voltage and High Voltage) and MW Re–Dispatch.

3.2 Functional design considerations

Based on the challenges described in 2.1.1, the following functional design considerations have been considered to guide the service definitions:

- There is a need for voltage support in the South East transmission network, particularly during periods of high generation (transmission and distribution connected generation), high interconnector import and low system load, as shown in Figure **2**.

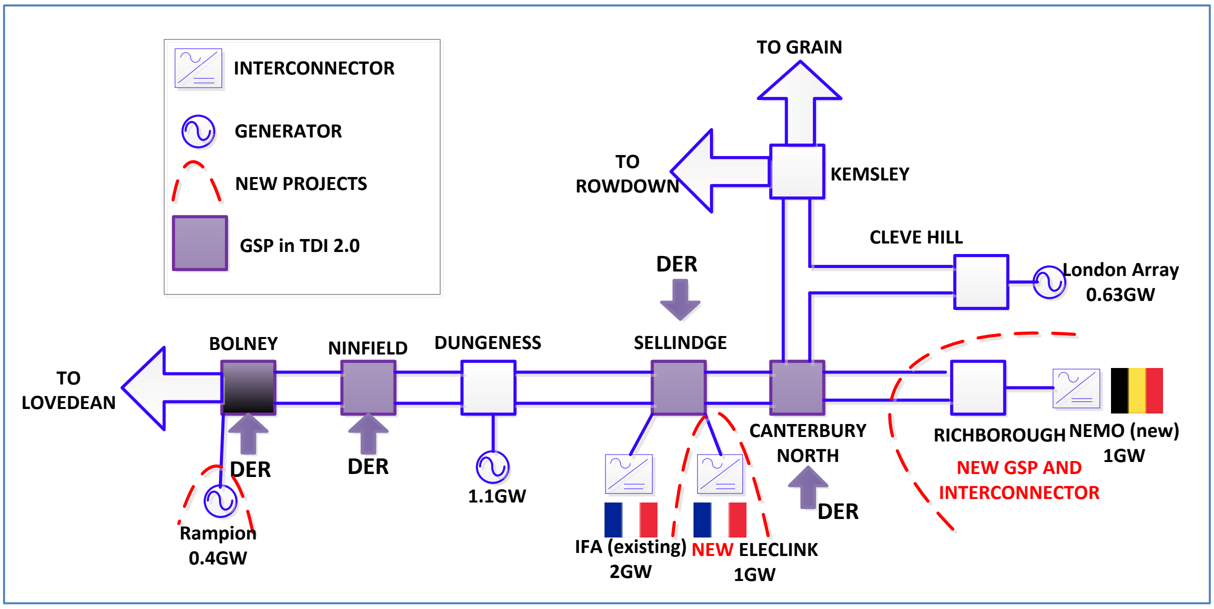

Figure 2 - South East transmission system showing main sources of generation & HVDC interconnection

- Under these conditions, and following a critical contingency of a double circuit fault between Kemsley, Cleve Hill and Canterbury (see Figure **3**), the 400kV system voltage would reach the System Security and Quality of Supply Standard (SQSS) planning limit of 95% of nominal value (after transformer tapping) Reference [4]. This is caused by the large power flow along the long transmission lines towards the west.

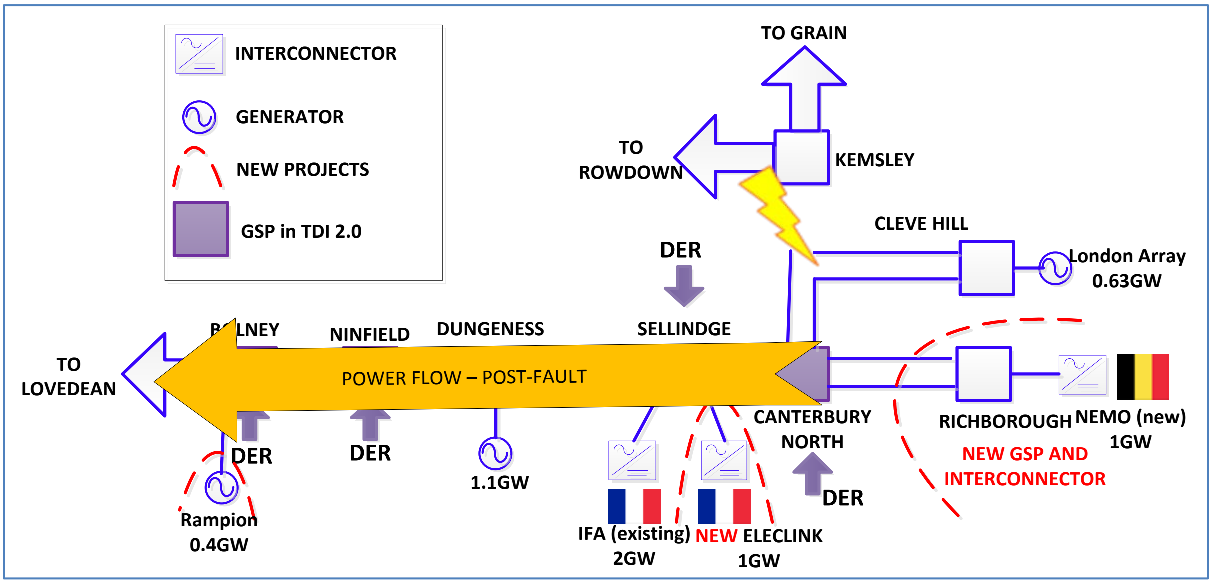

Figure 3 - South East transmission system power flow direction (yellow arrow) after critical contingency

- Additionally, during the same system conditions, a 'steady–state' high system voltage can exist predominately due to lightly loaded transmission lines and low distribution system reactive power consumption.
- DER connected at the distribution network have the potential to provide reactive power support during low and high voltage conditions.
- The voltage support from DER could be delivered to the transmission system similar to that provided by large generators (e.g. windfarm, SVC or STATCOM) connected at transmission network. The dispatch of the services should be kept as simple as possible for the users in the National Grid control room.
- The proposed response from DER should not cause any operational issues at distribution network.

3.2.1 Voltage control in wind turbines

Moeller & Poeller (MPE) have been commissioned to inform what would be the optimal control system conceptual design to meet the aforementioned design considerations. It was concluded that the control system could be based on modern windfarm control where the wind turbines are used to deliver reactive power at a remote connection point.

Wind turbine control is based on dynamic requirements set out in the Grid Code where it states that voltage support should be delivered in the form of voltage droop control. This means that if voltage drops at the connection point, the wind farm must inject reactive power in proportion to the voltage change in order to support the wider system voltage. Conversely, if the voltage increases, the wind farm should absorb reactive power to help bring the voltage back towards the desired value (see Section 5.4 for more information on the voltage droop concept).

In order to achieve these requirements, wind farm designers have produced a control design with a fast control loop (local to each turbine), and a slow control loop which ensures that the exact requirement is delivered at the connection point. Figure 4 shows the fast loop control where the turbines control their terminal voltage to a target value. As this control is local, and enacted by the inverters, it can be exceptionally fast (within a few milliseconds). This ensures that if the wind farm is subject to a voltage change, then the majority of the response is delivered very quickly.

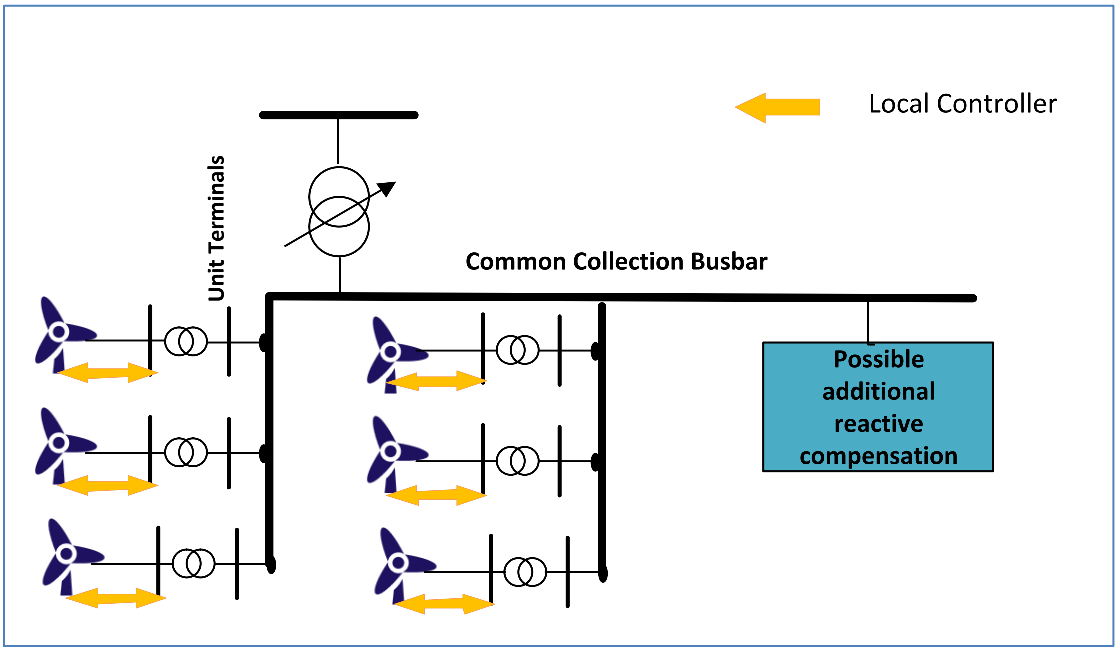

Figure 4 - Example wind farm showing the fast loop voltage control local to the turbine

However, it is not possible to successfully deliver the voltage droop characteristic at the connection point accurately by using this method. To achieve this, a 'central controller' has been included which measures the voltage and reactive power at the connection point, and subsequently adjusts the voltage targets of each individual turbine to achieve the overall desired response (see Figure **5**).

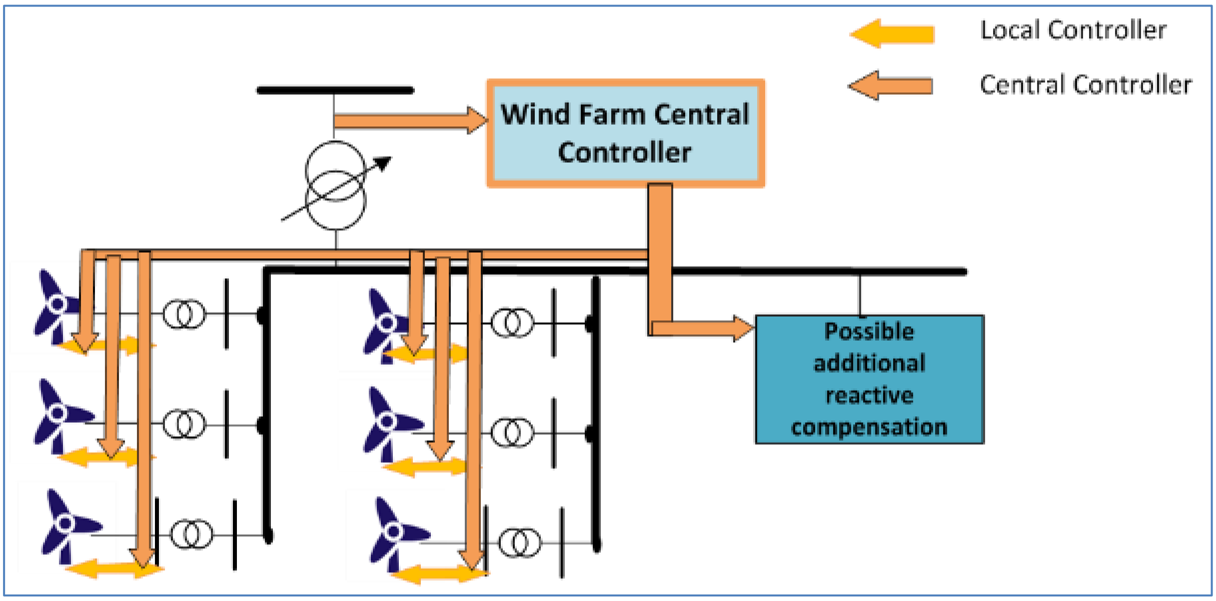

Figure 5 - Example wind farm showing addition of wind farm central controller

3.2.2 Voltage control in the TDI 2.0 project

In order to expand the concepts used by wind farms for voltage control, it is possible to make the following assumptions for the TDI 2.0 project:

- The individual turbines in the wind farm example are equivalent to one DER; and
- The connection point in the wind farm example is equivalent to the boundary at the high voltage side of the 400kV SGTs at each of the four GSPs in the project shown in Figure 2.

However, key differences have been considered during the design of the control system for dynamic models by MPE in Reference [2] listed as follows:

- The TDI 2.0 project utilises a full distribution network which has customers connected within who must be protected from voltage deviations and thermal overloads which can affect assets;
- The distances involved between the GSP and the DER point of connection are typically much larger than that of a typical wind farm providing this control approach;
- The DER could be from different technology types, manufacturers and sizes with different control requirements; and
- Voltage and loading of equipment must be managed within required values to ensure that the distribution system will be secured during the provision of the services.

Figure 6 shows a simplified example distribution system containing five GSPs (shown in blue boxes and connected by transmission lines), several distribution busbars (thick black lines), and DER connected in the distribution network.

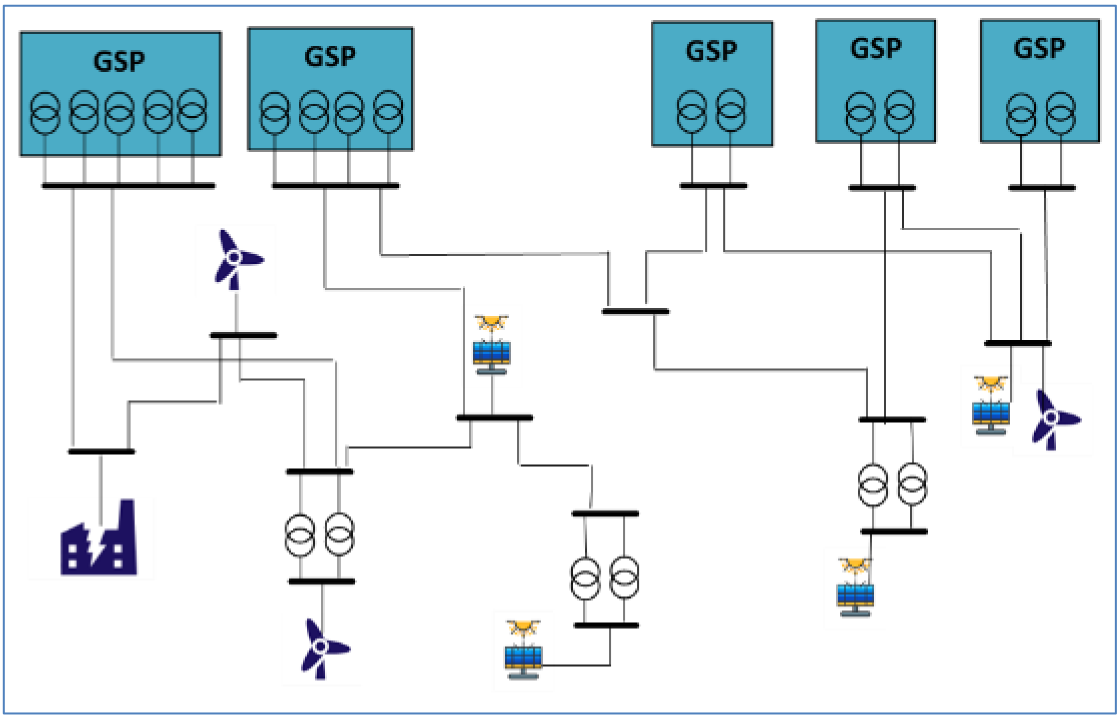

Figure 6 - Simplified example distribution system

The proposed control paths are presented in Figure 7. The general approach for TDI 2.0 voltage control services is that once the system is “armed” by the Electricity National Control Centre (ENCC), the individual DER are instructed to operate in voltage droop control mode, indicated by the red circles. Voltage droop is used as it ensures control of voltage in the distribution network within pre–defined limits and allows a rapid response to large voltage changes. In this proposed approach the “fast–control” loop is performed by the each DER smart inverter, whereas the “central controller” is the DERM system, installed in UK Power Networks’ control room, which coordinates the services. This technical control strategy would need to be supplemented by a commercial framework that structures the procurement of the services.

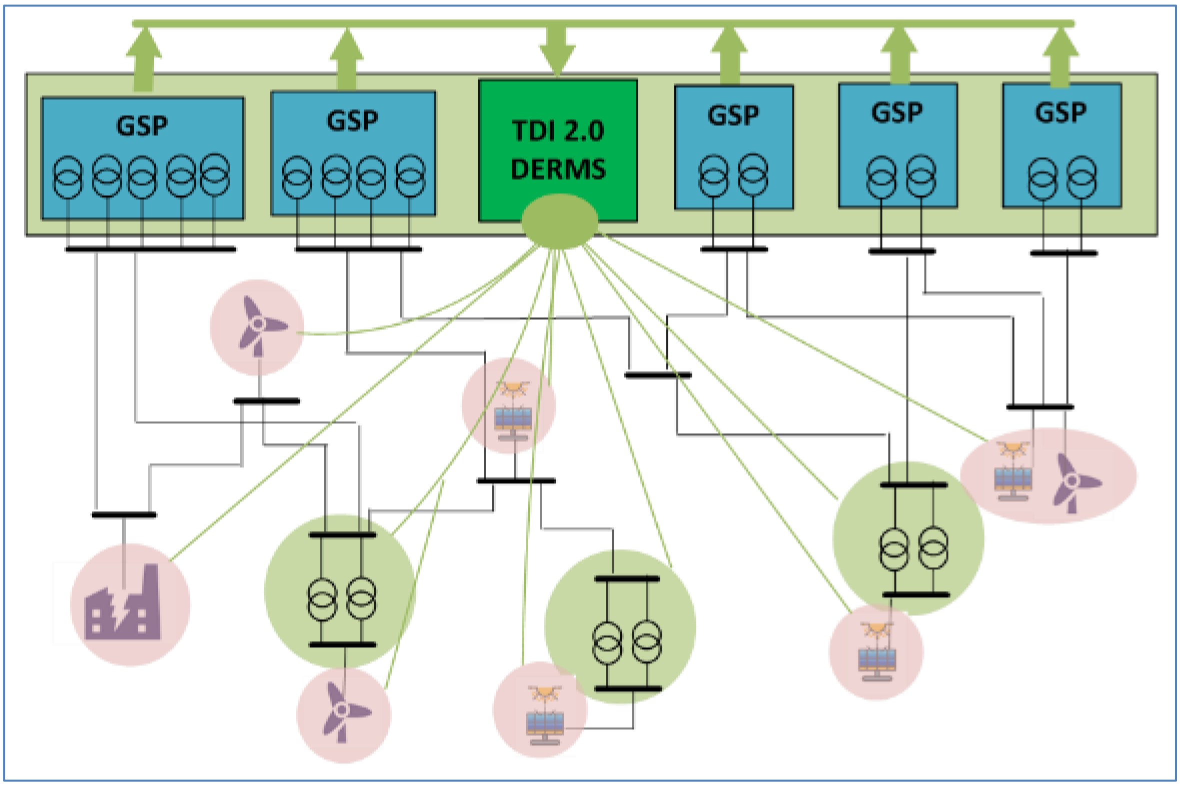

Figure 7 - Simplified example distribution system with TDI 2.0 control paths

3.3 TDI 2.0 Services

The project will facilitate the following services:

- Dynamic Voltage Control consisting of:
  - Dynamic voltage service (for Low Voltage management).
  - Dynamic voltage service (for High Voltage management, previously named steady–state voltage service).
- Constraint management service using re–dispatching of MWs.

The dynamic voltage control are Reactive Power Services and constraint management service is an Active Power Service.

These services will be coordinated by the DERM solution installed in UK Power Networks' control room with interfaces to both National Grid and DER.

Reactive Power Services

Dynamic voltage control provides stability after significant network events by fast automatic changes of reactive power. UK Power Networks will establish the effectiveness of each of the potential providers relative to their location and the GSPs as suppliers more deeply embedded in the distribution network will be less effective in providing voltage support to the transmission system.

The reactive power services will be based on voltage droop control systems installed on the DER as outlined in section 3.2.2. The DERMS will monitor the voltage and reactive power exchange at each GSP. The services are envisaged to operate as follows:

- Before an event (e.g. high or low voltage at transmission), it will control the voltage droop targets of the individual DERs so they achieve unity power factor to minimise reactive power generation or consumption when it is not required. However, this will only be maintained if the voltage is within a specified range at the point of connection.
- If a rapid voltage event occurs, then some of the voltage change will be reflected in the distribution system (before transformers begin to tap). As the DER are in voltage droop mode they will respond quickly and deliver a large portion of the required response.
- Simultaneously, the DERMS will measure the voltage change and instruct new voltage droop targets to each DER to maximise the post fault response.
- It is important that the transformers between the 400kV transmission system and the DER participating in the services are prevented from tapping as normal, as otherwise the voltage at distribution will be restored and the reactive response delivered to transmission will be reduced. Therefore, initially the transformer taps could be frozen and then optimised by the DERMS.
- A similar response is expected for transmission system high voltage, although this may not be triggered by a rapid event, and could be more of a gradual voltage rise due to decreasing system load.

Active Power Services

Active power services can be re–dispatched [2] in real time by National Grid or UK Power Networks such as that request will be within the envelope of UK Power Networks' constraints on the network.

All services will include the following time periods:

- **Sensitivity Calculation:** Includes the calculation of a sensitivity map for DER (participating or to inform future participants) which shows the relative effectiveness of their MVAr and MW re–dispatch services in the GSP, per season and per major network reconfiguration. This calculation can be refreshed from six months to up to a month depending on the information required by the DER and National Grid.
- **Day Ahead:** Requires running an optimisation routine which includes maximising the DER declared availability to calculate the aggregated availability of each service per GSP whilst minimising costs for the balancing mechanism. This optimisation routine shall consider distribution network constraints, contingency analysis, tap changer control optimisation and outages (present and future).
- **Service mode (real time):** Runs an optimisation in real time after a service request has been received to calculate the required set–points per DER to achieve the requested response. In case of a service instruction, the solution will need to run an optimisation routine in less than 10 seconds with the objective to calculate the DER set points to achieve the required GSP availability. If the service level cannot be met due to unforeseen circumstances, it should amend or reject the service request from National Grid.

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[2] DER can potentially already be dispatched by UK Power Networks if they are connected under a flexible connection and being curtailed by an active constraint. This action would be coordinated by an ANM controller in the area.

3.4 Functional Design

The functional design considerations outlined in section 3.2 have provided the basis on how the services could be defined and the interactions between each actor (National Grid, UK Power Networks and DER) to achieve this novel control approach. This section provides a description of the services definition presented in more detail Appendix A, Appendix B and Appendix C. It provides an overview on how each service is envisaged to work in various timescales. It also defines the main DERMS characteristics required for the service provision.

If is envisioned that the DERMs will have three main components which will interact to facilitate the services being provided:

- Forecasting;
- Optimal Power Flow – OPF (including power flow); and
- Control and dispatch.

In the descriptions that follow, the interaction between these functions is highlighted.

3.4.1 Sensitivity Calculation

The main goal of the Sensitivity Calculation time horizon is to calculate a sensitivity map showing DER effectiveness depending on the location of the DER, network configuration, seasons and possible contingencies. It is envisioned that this map will be made available via a web interface to National Grid and DER. This map will enable new and existing DER to view how effective their services are at the GSP and can provide locational signals on where it could be more financially beneficial to connect a new DER project.

The sensitivity calculation process will be performed in a similar way for all TDI 2.0 services. It starts with gathering the data required to run a power flow analysis. The anticipated inputs to the sensitivity calculation include:

- Long–term availability of the DER (including planned outages and maintenance), historical data for generation and demand from National Grid and UK Power Networks (as power flows affect sensitivity factors);
- Regional Network Model including the transmission and distribution models of the South East;
- Planned outages and major seasonal network reconfigurations from UK Power Networks and National Grid; and
- National Grid and UK Power Networks critical contingencies that need to be considered.

3.4.2 Day Ahead

This time horizon will require running an optimisation routine which includes maximising the DER declared availability to calculate the availability of each service per GSP whilst minimising costs of providing the service to National Grid. This optimisation routine will include distribution network constraints, contingency analysis, tap changer control optimisation and outages (present and future). The outputs will includes a market view of services in the form of a cost curve per GSP and per service updated every 10–15 minutes in a rolling window.

It is envisioned that the Day Ahead time horizon will be similar for all the TDI 2.0 services. It will require two main functions to be run in the DERMS which are Forecasting and Optimal Power Flow.

In **Forecasting**, the main goal will be to calculate the forecasted demand and generation data required for the Optimal Power Flow function to calculate the availability of the service. The inputs to the forecasting function include data and information such as DER availability, costs, weather forecast and historic demand/generation profiles as well as information regarding other services procured in the area from UK Power Networks and/or National Grid.

The outputs of the forecasting function will be entered into the Optimal Power Flow tool in the form of forecasted service capability per DER, service costs, forecasted MW and MVAr output of DER and forecasted demand (MW and MVAr).

In addition to the forecasted data, DER bids, DER technical capability at the Point of Connection (POC), network configuration from SCADA and planned outages are inputs to the optimisation engine. The **Optimal Power Flow** should calculate the service available to National Grid. This function estimates the maximum service response that can be achieved in each GSP that incurs the lower cost and does not have any detrimental effects to the distribution network. The DERMS should find a solution taking into account DER response times, contingencies, planned outages and potential conflicts with other services.

3.4.3 Service Mode

The main goal of this time horizon is to deliver the service required and requested by National Grid. Depending on the service being procured, it is envisaged that this time horizon will work differently. The following summarises the main processes anticipated for service provision.

3.4.3.1 Dynamic Voltage Service – Low Voltage Use Case

The Dynamic Voltage Service (Low Voltage) Use Case presented in Appendix A provides a flow chart (use case) view of how the service it is envisioned to work in all time horizons.

When the Service mode is not "armed" the DERMS solution will allow DER to operate as normal (e.g. unity power factor control mode at the DER). When the DERMS solution receives an arm signal from National Grid, it also receives droop characteristics (or a voltage set–point) required at the interface point (per GSP) similar to Figure 8.

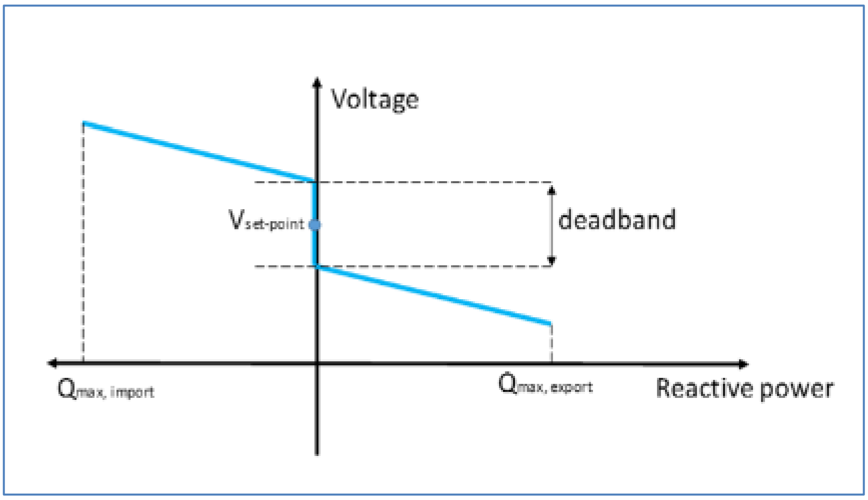

Figure 8 - Voltage Droop Characteristics.

The DERMS then changes participating DER to voltage droop control mode and gives required or revised voltage setpoints to maximise their response. The setpoints are calculated with the Optimal Power Flow function which requires the same inputs as described in Section 3.4.2.

The output of this calculation is the DER and tap changer set–points to achieve the response should a low voltage situation occur. DER and tap changer dispatch should be achieved in less than 10 and 30 seconds from National Grid's instruction respectively.

If and when a fault occurs, a rapid voltage drop that exceeds a pre–defined dead band should cause armed DER to automatically react (self–dispatch through droop control using latest stand–by settings) and support the voltage. Response should be achieved in no more than 1 second. The inputs required for this emergency control are largely the measured values from SCADA data from National Grid and UK Power Networks.

3.4.3.2 Dynamic Voltage Service High Volts (Previously called Steady State Response)

The previously named Steady State Response service has been re–phrased as "Dynamic Voltage Service for High Volts" as the mechanism of instruction and sensing will be largely the same as the low voltage case. This use case is presented in Appendix B.

The main goal of this time horizon is to deliver the service required and requested by National Grid. When the DERMS is not "armed" DER will be allowed to operate as normal (e.g. unity power factor control mode at the DER). Once an "arm" instruction and droop characteristics required at the interface point (per GSP) is received from National Grid the solution changes participating DER to voltage droop control mode and gives required or revised voltage set–points to maximise their response. In order to calculate these set points, an Optimal Power Flow will be required described in Section 5.3.4, but instead targeting high voltage issues. Given that high voltages issues will not materialise at the POC of the DER (unlike the low voltage case), it is necessary to rapidly re–calculate the required voltage set–point to achieve the response based on the actual voltage at the GSP.

Once the set–points have been calculated by the Optimal Power Flow, they are sent to the DER and respective tap changers. The timing of the service should be no longer that 30 seconds from National Grid's instruction (or from the detection of high voltage in the GSPs). This service will also have an element of self–dispatch from the DER which should take no longer than 10 seconds.

The DERMS will monitor each GSP's response and DER output (continuous check for the duration of the time step). If required response is not achieved, it is expected to re–run the power flow with new current network state. After the time specified in National Grid's instruction has passed or the voltage is return within the deadband, the DERMS will disengage DER.

3.4.3.3 MW Re–Dispatch (Active Power) Service

The main goal of this time horizon is to deliver the service required and requested by National Grid. Once an instruction is received from National Grid expressed in terms of MW response and time, the optimal power flow will run to calculate the set point to achieve the required response from National Grid avoiding any detrimental effect to the distribution network taking into account planned outages. The solution must ensure that it estimates the DER MW capability to be offered to National Grid after having considered the amount of MW curtailment needed to cater for distribution constraints.

4. ICT Design Options

Introduction and Problem → Services Definition → **Architecture Design** → Commercial Considerations → High Level Business Processes → Synergies and Conflicts → Summary

The purpose of this section is to explore and compare available design options for the project in order to select the best options whilst being mindful of the need for integration with the existing infrastructure of UK Power Networks and National Grid. The key aim was to select the options that are in line with the business strategies and can be supported and scaled up in the future.

Alongside UK Power Networks' architectural principles and standards the options also must adhere to the following project principles/constraints:

- Time: to enable the trials to commence, the solution must be delivered within the project delivery timescales of 2017 to 2018 as per the project phases (See Figure 1);
- Costs: the cost of the solution must be within the allocated budget;
- Scalability: the design should be scalable to expand to other DNO regions and to include new smart grid functions; and
- Future–proof: the design should be in line with relevant UK Power Networks' strategies so as to have adequate support and maintenance arrangements for the future of the solutions.

4.1 Architecture Options

4.1.1 Existing High Level Architecture

In order to effectively carry out the gap analysis it is essential to represent the existing UK Power Networks' architecture. The current high level architecture and integration for the areas relevant to the project are detailed in Figure 9 below. The diagram shows the applications and the data objects, which have been highlighted as candidates for potential re–use for the TDI 2.0 ICT solution.

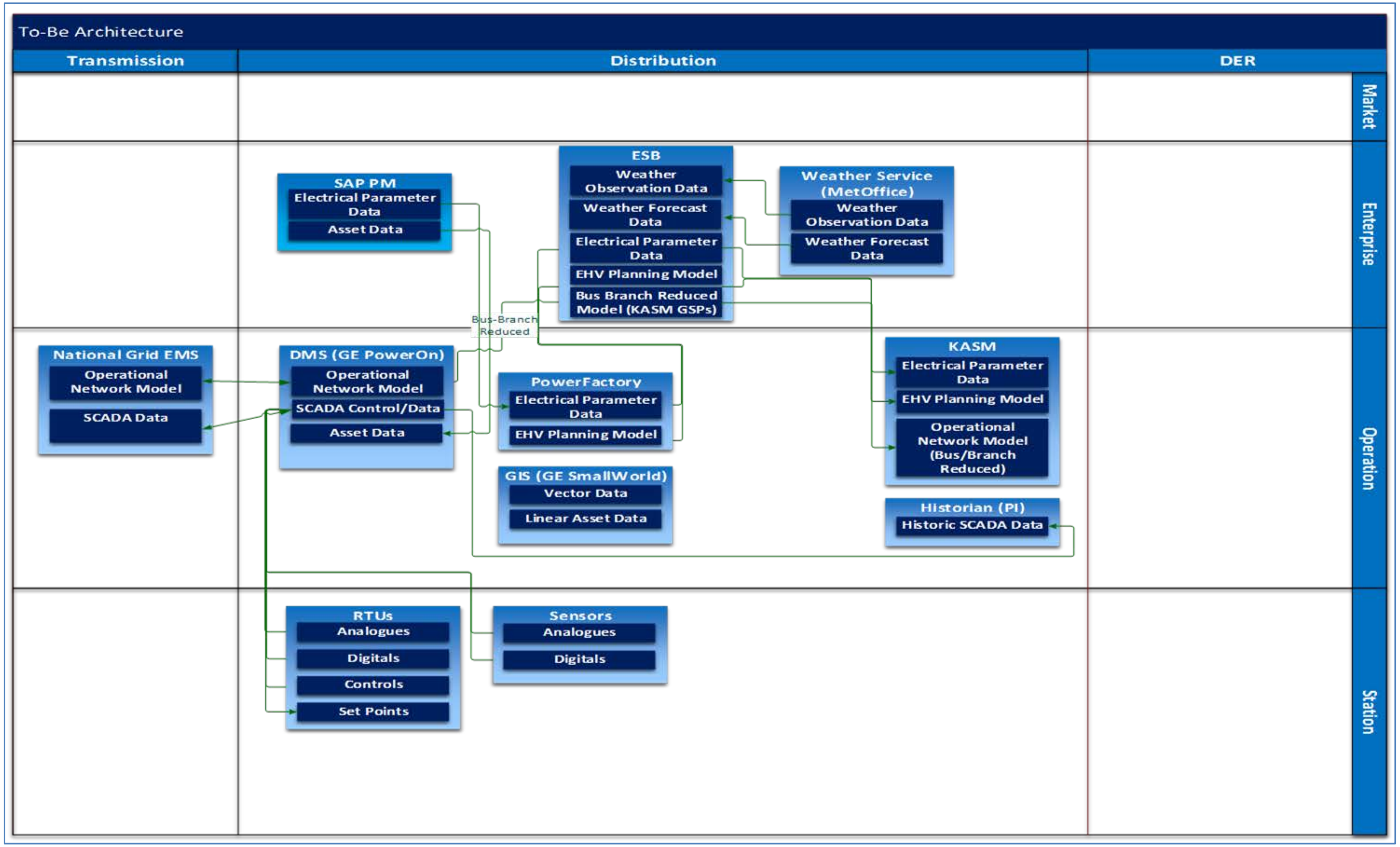

Figure 9 - Existing high level architecture based on functional layer of Smart Grid Architecture Model (SGAM)

During design workshop sessions, key UK Power Networks stakeholders went through the various design options as part of the gap analysis phase of the project. In these sessions, all areas of the solution were investigated and optimal solution designs identified. The following sections detail the available options and the decisions made for each of the areas of the design.

4.1.2 Design Considerations

The project requires multiple functions and solutions to be integrated together. The following design considerations are required to be made for the high level design:

- **Physical System Hosting Infrastructure:** The solution is a future control system application and hence is expected to be located at the UK Power Networks' Control Centre environment as per the existing control system applications. However, in order to meet performance demands, and scalability requirements, hosting portions of the TDI 2.0 system within a cloud platform[3] may prove more effective.
- **Communications & Integrations:** The project will use open standard protocols such as Distributed Network Protocol 3.0 (DNP3), Inter–Control Centre Communication (ICCP), and web services using Enterprise Service Bus. Different components within the system have different communications needs, and so consideration needs to take into account the type of components communicating, the data transfer requirements, and security requirements of the components.
- **Data Modelling:** IEC CIM (Common Information Model) is the industry standard for data model exchange and appropriate for some of the data transfer in the system. This is the preferred option for data exchange between systems, but is dependent on the development of a model export function.
- **Data Storage:** The real time service event and control data is expected to be stored in PI historian. However, the storage of power system analysis results and scenarios are expected to be stored within the DERMS. Commercial data regarding DER bids, availability and outturn should be made accessible to all systems that require access to it.
- **Security:** The security requirements of each component in the solution and integration between those components must be taken into account. Each component and integration will have differing legal, cyber, industry, and corporate standards and policies which they must meet. The impact of existing security arrangements must also be accounted for.
- **Application Impact:** Impacts on existing systems and applications must be accounted for in design, and a principle of 'minimal change' applied. Integration with existing systems should ideally have no requirement to change those systems, and where change is necessary to support the newly integrated components, that change must be impact assessed and the least invasive change designed to avoid risk to existing business processes.
- **Commercial Services:** These are based on the requirements set out in Section 3 for TDI 2.0 commercial services.

4.1.2.1 Network Connectivity Model

TDI 2.0 will require an accurate network connectivity model with asset electrical parameters describing both the as–built and operational live network. There are two options for the creation and maintenance of this model:

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[3] Platform as a service (PaaS) is a category of cloud computing services that provides a platform allowing customers to develop, run, and manage applications without the complexity of building and maintaining the infrastructure typically associated with developing and launching an application.

- **PowerFactory DigSILENT**
    - Within UK Power Networks and National Grid, DigSILENT is currently used for the planning purposes and is capable of carrying out complex power system modelling and analysis.
- **GE PowerON**
    - Within UK Power Networks, GE PowerON is used as the Distribution Management system (DMS). As part of the deliverables from the KASM project PowerOn also contains the South Eastern section of National Grid's network, including real time SCADA data.

GE PowerON has been chosen as the source for the network model, as it is in keeping with UK Power Networks' strategic direction, and it accurately represents the state of the distribution network. PowerFactory DigSILENT is not deemed adequate for the project to meet the service requirements in terms of representing the current operational state of the distribution network. Furthermore it currently does not have a complete 11kV network and requires manual updates to model alterations to the network, neither of which are limitations of GE PowerOn.

4.1.2.2 Real Time SCADA Data

The real time SCADA data consists of plant statuses (digital indications), measurement data (analogues) and control signal data. These are needed to correctly represent the status of the network which will improve the accuracy of the services provided. Two options are available:

- **Direct from substation**
    - There is an option to receive real time SCADA data directly from substations via Remote Terminal Units (RTUs) and smart sensors/devices. This approach is currently adopted by UK Power Networks' Active Network Management (ANM) system whereby the RTU operates in a dual hosting mode to send data to both the PowerON Distribution Management System, and the ANM.
- **Distribution Management system (DMS) – GE PowerON**
    - The UK Power Networks DMS is GE PowerON, an application that receives real time SCADA data from substations via RTUs. As the PowerON application already processes a variety of data and is maintained as a high availability critical application, there is long term benefit in utilising it as the central hub to provide real time data to multiple applications. This approach can offer two key benefits; firstly, it can avoid duplication of SCADA data maintaining a single route for SCADA data from both transmission and distribution networks; and secondly, it can reduce the burden on SCADA communications network by half by transmitting one set of data instead of two.

The DERMS will receive real time data via GE PowerON. It is envisioned that ICCP links to GE PowerON bring several benefits as hardware and the software to deal with RTUs communicating back to UK Power Networks' estate is already in place, and supported by teams who are familiar with deploying and configuring these devices. This option also benefits from resilient communications, as UK Power Networks' has developed a solution that supports both satellite and 4G communications, and will failover from one to the other automatically if the RTU is unable to reach the GE PowerON SCADA Front End Processor (FEP).

4.1.2.3 Real Time SCADA Data (DMS Real Time Data to TDI 2.0)

In addition to the real time SCADA data coming in from DER RTUs in the field the TDI 2.0 solution will also require real time data from other RTUs and also any manual switch states. This will provide a real time view of the network state and enable the Optimal Power Flow to correctly model the network. To achieve this there are three options:

- **Web Service Integration**
    - Develop a new interface to allow the DMS to send outbound messages as state changes occur. This interface does not currently exist and would be an additional piece of functionality which would need to be provided by the DMS vendor. It would allow easier integration as the messages would be in a widely accepted format, either JSON or XML.
- **DNP3**
    - DNP3 is a widely used SCADA protocol and allows for synchronous messages to be communicated between devices/systems. This would require additional configuration for each point to duplicate the data from the DMS to the TDI 2.0 solution. DNP3 is open standard protocol which allows for easier integration with potential vendor solution.
- **ICCP**
    - ICCP is a protocol designed for control system to control system integration. ICCP has already been implemented between UK Power Networks and National Grid for the KASM project and enables sharing of real time data between the two parties. It is configured by using a subscriptions table and allows multiple subscribers to the same data points. It is an open protocol so again would allow easier integration with potential vendor solutions.

It has been deemed appropriate that any real time data should be sent between systems using an IP based SCADA protocol, which rules out the web service integration method. However, the final decision on the protocol to use will be defined within the detailed design phase with the successful vendor for the TDI 2.0 DERMS.

4.1.2.4 DER Control Interface

The DER control interface is required to enable the TDI 2.0 solution to send SCADA controls to the DER participants' hardware to request services offered or to pre–arm their installations for low or high voltage scenarios.

- **PowerON functions**
    - The DERMS solution could send all control signals via PowerON.
- **New DER control solution**
    - The DERMS solution could send all control signals directly to the DERs from a new DER control solution

PowerON can provide a single interface to substations, aggregators, and DER participants. Direct interface from DERMS solution to the DER control solution may remove any possible delays in executing controls, reduce the complexity of integration within the DERMS solution, however re–use of the existing PowerON's SCADA Front End Processor (FEP) could be more effective for the project.

4.1.2.5 Infrastructure Hosting

Newly procured components for the DERMS solution need to be hosted on physical infrastructure. There are different options available for this hosting to ensure that UK Power Networks' required performance, resilience, and cost requirements are met.

- **On–premise**
    - New components for the DERMS solution are hosted wholly within UK Power Networks' existing data centres located at the control centres.
- **Cloud**
    - New components for the DERMS solution are hosted wholly within the platform of a cloud infrastructure provider, to take advantage of the abilities of cloud infrastructure to quickly scale for performance, and cost efficiencies of the consumption model cloud infrastructure uses.
- **Hybrid**
    - New components for the TDI 2.0 solution are hosted in a mix of on–premise within UK Power Networks' existing data centres, and within the platform of a cloud infrastructure provider as appropriate to the performance and resilience requirements of the individual component.

The detailed design of each new component will determine the physical hosting type used by DERMS. The logical design of the infrastructure will be the same irrespective of the eventual option chosen.

4.1.2.6 Communication Interface Topology

The communications interfaces for the DERMS solution will form a topology and the make–up of that topology will influence the implementation and future maintenance and extensibility of the solution. Whilst there are many different topologies available, three options are appropriate for DERMS

- **Point–to–point**
    - The simplest topology with dedicated link between two components.
- **Bus**
    - A topology in which components are connected to a common linear component called a bus that is responsible for brokering communications between components.
- **Hybrid**
    - A topology consisting of a mix of other topology types.

The DERMS solution is required to run deterministic[4] algorithms to carry out monitoring, analysis, optimisation and control functions and as such, all deterministic signals will be exchanged using deterministic protocols. The non–deterministic data will be exchanged using open standard and interoperable interfaces. The detailed design of each component within the DERMS solution will influence the topology in use. Some components will require direct point–to–point interfaces, for example, the communication between National Grid control systems and UK Power Networks' control systems due to the nature of the protocol in use and the security requirements of the interface. However, some components will utilise standard internet/intranet–based communication mechanisms such as web services, and in this instance, a bus topology using the existing UK Power Networks' Enterprise Service bus which is part of the UK Power Networks' existing capability. Thus, the ultimate topology determined in detailed design will be a hybrid that promotes re–use of existing services for efficiency.

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[4] A deterministic system is one in which the system can only be in one of a set of pre-defined states at any point in time, and it can only move from one state to another state when defined conditions are satisfied. The future state of the system is determined by the current state and the conditions satisfied.

4.2 Design Options Summary

4.2.1 Proposed Solution Architecture

Based on the design decisions made in the above sections and adhering to the requirements of the project the proposed solution architecture is detailed in Section 6.

5. Power Systems Design Options

Introduction and Problem → Services Definition → **Architecture Design** → Commercial Considerations → High Level Business Processes → Synergies and Conflicts → Summary

This section explains the techniques required to enable the DERMS Solution to be deployed in the DNO network and to achieve the project’s functionality where services are procured by National Grid from UK Power Networks.

As described in section 3 , the main functionality required for the solution is to be able to perform the three main commercial services for the project. Each of these services has three time horizons which the DERMS must operate under:

1. Sensitivity Calculation: which calculates the long term availability of each service;
2. Day ahead: which estimates the available response one day ahead (a rolling 24–hour window) and calculates the associated costs; and
3. Service: which delivers the actual service (DER and Tap Changer Dispatch).

This section describes the power systems related components of the TDI 2.0 project which allow DER to actively contribute to alleviating constraints on the transmission network, via the provision of the above services in each of the three time horizons. These components include:

- State Estimation requirement;
- Forecasting function;
- Optimal Power Flow function, including the Load Flow Calculation engine; and
- Reactive and Active power control from DER.

It includes considerations of the various options available to perform the required functionality, and the rationale behind the decision as to which is believed to be best suited to the DERMS application.

5.1 State Estimation

In order to provide the functionality required in the DERMS application a network model must be produced and analysed so that service performance can be assessed and validated against real measurements. However, in practice, central visibility of all electrical quantities (e.g. V, I, P, Q, phase–angle) at all substations within a distribution network is not available, as:

- Sites can be remote from telecoms networks, and it can be costly to provide high bandwidth services;
- The instrument transformers required to provide measurements are costly and their use is kept to a minimum;
- Accurate and reliable measurement of these quantities are not required for normal operation of the network; and
- Data might be available but contain inaccuracies due to measurement errors or latency.

State Estimation is a technique that uses the current set of available system measurements to estimate the electrical magnitudes and angles for each node in the network. The output of the tool is an approximation of the network based on the input conditions that can be used as a basis for further analysis.

For each of the three services that will be provided by the project, in each of the three time horizons, a model of the network must be analysed so that the impact of the DER and transformer tap changer actions can be determined. Hence, the DERMS solution should include a State Estimation tool in order to derive the electrical quantities required in the Optimum Power Flow and Load Flow components that are described in following sections.

5.2 Forecasting function

The DERMS solution is required to include a Generation and Demand forecasting function to estimate the network parameters in the day–ahead and intra–day calculation of service availability. The forecasting tool is crucial for planning accurate network operating conditions based on the historical pattern of demand and generation as well as weather predictions. This will result in the DERMS being able to accurately account for service availability to National Grid.

The forecasting component should be able to process information about the network, historic generation and demand, DER capability and availability, and the weather. It can use this data to calculate the maximum available MVAr/MW available per DER, which is envisaged to be used by the Optimal Power Flow function to calculate the available service level per GSP for each of the three services.

The output from this function will be fed into the Optimal Power Flow function, described in the next section and parameters are to be calculated from either 24 hours to half–hourly for day–ahead or intra–day output.

From the use cases presented in Appendix A, Appendix B and Appendix C, it can be seen that the forecasting tool will be required to map the complex relationship between a large number of relevant input variables, and produce the output required by the Optimal Power Flow function. As the relationships between the variables cannot be initially defined or solved using rule based programming, a learning process is required that will develop rules based on the outcome of training examples and previous iterations. As such, some form of Artificial Intelligence[5] based logic is required, such as a Fuzzy Logic Engine, an Expert System or an Artificial Neural Network (ANN). In this instance, the forecasting options proposed by DERMS providers have been based on ANN. ANN techniques are used for solving problems that are too complex for conventional technologies or those types of problems that do not have an algorithmic solution. ANN has proven to be a suitable approach for providing reliable forecasting solutions based on industry research[6].

5.2.1 Artificial Neural Networks (ANN)

ANN are software systems based on a large number of connected simple blocks (neurons). The connections between the neurons carry signals, the magnitude of which is determined through weightings. When the incoming signals to a neuron reach a set threshold it becomes active, and an output signal is transmitted to the neurons connected to it, again via weighted paths. Typically, ANNs are arranged in several layers, containing an input layer, an output layer and a number of intermediate layers as shown in Figure 10.

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[5] Artificial intelligence can be defined as development of machines and software that can simulate human-like or intelligence behaviour including decision making in complex environments based on previous decisions.

[6] A. Badri et al, "*Application of Artificial Neural Networks and Fuzzy logic Methods for Short Term Load Forecasting"* in Energy Procedia vol 14, 2012

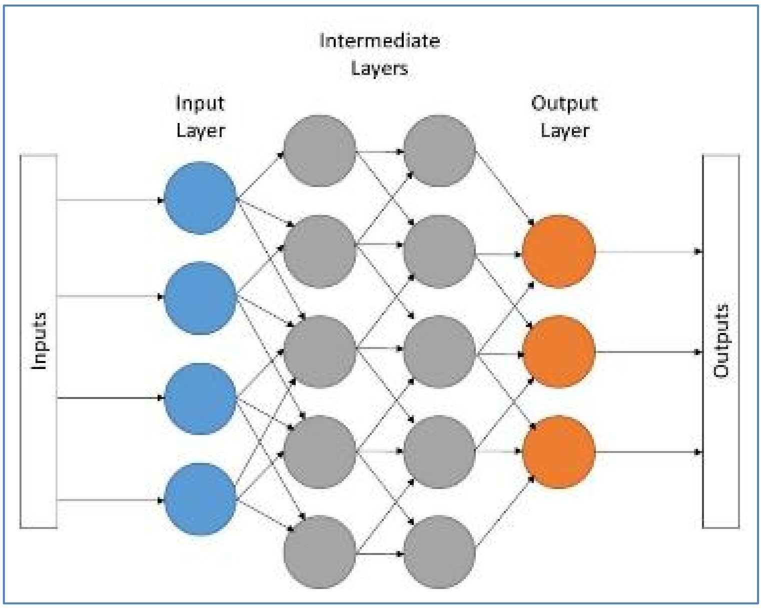

Figure 10 – Example ANN structure

Figure 10 shows an example of an ANN network structure. The input layer represents the information that is fed to the ANN logic. Then, this information is processed in a set of intermediate layers where a series of formulas are applied to the data depending on the outputs required. This intermediate layers can be comprised of weightings, formulas or algorithms that facilitate the decision making of the neural network. The output layer will present the information once processed by the intermediate layers.

ANN are suited to applications where a function must be inferred from observations, and in particular, where the complexity of the data makes the development of the function through a procedural code difficult. As such, ANNs are an appropriate tool for use in complex control and data processing tasks, such as the forecasting tool required in this application.

The ANN forecasting application can also be integrated with machine learning to build reliable and accurate forecasting models based on historical and real time data, allowing a wide range of input variables to be correlated with DER production and network demand.

5.2.2 Forecasting Engine in DERMS

TDI 2.0 will require the ability to forecast generation and demand to accurately calculate service availability in the Sensitivity and Day–Ahead time horizons. The functionality required in the DERMS can be achieved in by either:

- **A new forecasting solution**
    - Procure a DERMS with a built–in forecasting engine that can be used in other future solutions.
- **Kent Active Network Management (KASM) – forecasting tool**
    - The existing UK Power Networks' system KASM includes forecasting functionality.

The procurement of a forecasting engine embedded in the DERMS solution has been determined to meet the design principles of the project as it will decrease the integration needs with other applications. However, a provision has been made for the DERMS provider to be able to interface with KASM to leverage the forecasting points already provided by this tool.

5.3 Optimal Power Flow (OPF)

Traditionally the aim of an OPF tool is to determine the most efficient operation of a given network, attempting to achieve one or more objectives such as minimising network losses, minimising operating costs and maximising power output.

The OPF will determine the optimal operating point of the existing network in terms of control inputs such as tap changers, sources of reactive power compensation and DER real and reactive power settings for various network constraints. OPF tools can optimise across a number of these objectives by assigning appropriate weighting values to each.

The OPF function for DERMS will be comprised of a load flow calculation engine that is able to run different optimisation routines depending on the time horizons described in section 3.3.

The DERMS shall interface with DER, National Grid and UK Power Networks systems to produce and maintain real time availability and capability data for service response taking into account the current state of the distribution network, contingencies and forecasting. In order to do these tasks, the OPF function is envisaged to:

- Receive forecasted data from the forecasting function;
- Run contingency analysis of pre–determined key faults in the network to ensure that the service availability calculated will not be in detriment to the distribution network;
- Use the network model to run all load flow studies;
- Take into consideration outages in the area; and
- Consider service conflicts with other services being procured in the area; flag and resolve them considering pre–determined rules.

5.3.1 The OPF problem

The OPF problem can be stated as the need to solve the objective function:

$$\min f(\underline{x}) \; or \; \max f\left(\underline{x}\right),$$

where vector $\underline{x}$ consists of the state variables and control variables. This is subject to equality and inequality constraints:

$$P_{Gi} - P_{Li} - \sum_{\substack{j=1 \\ j\neq i}}^{n_{bus}} P_{ij}(V,\delta,t) = 0$$

$$Q_{Gi} - Q_{Li} + Q_{ci} - \sum_{\substack{j=1 \\ j\neq i}}^{n_{bus}} Q_{ij}(V,\delta,t) = 0$$

$$S_{ij} \le S_{ij}^{max}$$

$$V_i^{min} \le V_i \le V_i^{max}$$

$$P_{Gi}^{min} \le P_{Gi} \le P_{Gi}^{max}$$

$$Q_{Gi}^{min} \le Q_{Gi} \le Q_{Gi}^{max}$$

$$Q_{ci}^{min} \le Q_{ci} \le Q_{ci}^{max}$$

$$t_k^{min} \le t_k \le t_k^{max}$$

$$\emptyset_k^{min} \le \emptyset_k \le \emptyset_k^{max}$$

Where:

P_{Gi}, Q_{Gi}: Active and reactive power generation of DER at node i;

$\underset{x}{\rightarrow}$: State Variables (V_i, δ_i);

$\underset{u}{\rightarrow}$: Control Variables $(P_{Gi}, Q_{Gi}, P_{Slack}, Q_{Slack}, Q_C, t_k)$;

S_{ij}: The apparent power flow;

Q_C: The reactive power compensation at node i;

$\emptyset_k$: The angle of phase shifting transformer k; and

t_k: The tap position of tap changer k.

δ: Phase angle

In the DERMS application the objective functions to be implemented can be stated as:

- **Day Ahead:** An optimisation routine which includes maximising the DER declared availability to calculate the availability of each service per GSP whilst minimising costs for the System Operator. This optimisation routine will include distribution network constraints, contingency analysis, tap changer control optimisation and outages (present and future).
- **Service (real–time):** An optimisation routine with the objective to calculate the DER and tap changer set points to achieve the required GSP availability. It will also optimise voltage droop settings for each DER that deliver the required voltage droop response at the interface point. It will need to run the calculation in less than 10 seconds.

In order to perform OPF routines, a load flow engine must be available to calculate the parameters of the network.

5.3.2 Load Flow Calculation

A load flow calculation is used to determine steady state power flows in a network. The load flow calculation will output real and reactive power flows in circuits (P & Q), and voltage magnitudes and relative angles (V & δ) at the bus bars. In most power systems, the network is too complex to allow a simple solution to be derived for the load flow and, as the calculations that must be solved are non–linear in nature, an iterative computational approach is generally used. The most popular approach to solving the non–linear[7] system of equations is the “Newton–Raphson” method.

In the DERMS application, the load flow will be used to model the network performance under the various forecast conditions, and will be iterated to produce the optimised solution for each of the three services and in each of the three time horizons

In this application, an initial pass of the load flow calculation must derive P, Q, V and δ at every node, together with the sensitivity factors for each DER at its associated GSP. These sensitivity factors are required in order to determine the effectiveness of each DER in solving particular constraints, and therefore offering the required services. In this way, the OPF function can be simplified by only including the most effective DER in subsequent iterations of the load flow.

The architecture of the load flow engine in its relation to the OPF is important, as in the Service Mode, near to real–time operation is required. For this reason, the efficiency of the load flow package and the interface to it is critical in ensuring that the optimisation problem can be solved rapidly. The use of a bespoke and embedded Load Flow Engine, tailored to meet the requirements of this application,

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[7] A linear power system is identified when its parameters (resistance, inductance and others) do not change with a change in voltage and or current. Most power systems have non-linear attributes or equipment which change value with a change of voltage and/or current

would offer benefits in this regard. There are techniques available that merge the load flow network equations with the optimisation process, to solve the problem directly. The options considered to fulfil this requirement in the DERM specification are:

- **GE PowerON load flow engine**
    - Load flow functionality offered by GE PowerON.
- **New load flow calculation solution**:
    - Procure a new load flow calculation solution for use within DERMS.

Both options were included as part of the requirements to the prospective DERMS vendors. As part of the evaluation of vendor solutions, the inclusion of an embedded load flow calculation engine within the DERMS application was found to be the lowest risk option removing any integration needs.

5.3.3 Contingency Analysis functionalities

One of the key principles of TDI 2.0 is that services provided to National Grid from DER will not be in detriment to the distribution network. In order to comply with this premise, contingency analysis of critical faults will need to be performed to ensure that the availability calculation presented to National Grid will not cause further constraints in the DNO network. Two options were considered to embed contingency analysis into the DERMS functionality:

- **KASM Contingency Analysis tool**
    - A Contingency Analysis tool is being trialled as part of the UK Power Networks' KASM innovation project which also interfaces with National Grid and covers the East Kent network.
- **DERMS solution running contingencies from a list of key faults**
    - Procure the DERMS with a built–in contingency analysis function.

The preferred option in this case is to include contingency analysis functionalities in the DERMS requirements to remove further integration needs. The KASM Contingency Analysis tool will still be a key functionality in the control room and will provide the control engineers with additional information about the network at any given time. Therefore, when mapping the business processes described in Section 8, the interaction with the KASM contingency analysis has been accounted for.

5.3.4 Computational Approach options to OPF

There are two computational approaches to OPF:

- **AC Mathematical Optimisation**: A computationally intensive process that seeks to find the true optimal point.
- **AC Heuristic[8] Optimisation**: The approach seeks to reduce the calculation complexity, by focusing on specific areas for the optimal point, based on assumptions. Potentially, this approach may find only the local minima and not the global minima required.

In the DERMS application, a balance must be struck between the speed (and by association the computational complexity of the algorithm) at which the OPF component must provide its output (given the near to real time requirement in the Service Mode) against the need to find the optimal response. In this context the OPF finding only a local minimum may mean that an optimal response is

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[8] Heuristic can be defined as a process relating to exploratory problem-solving techniques that utilise self-educating techniques (such as the evaluation of feedback) to improve performance – Mirriam-Webster definition

found in terms of the service provision to the transmission network, without providing the optimal solution in the distribution network (for example excessive curtailment of generation or incorrect set points/tap positions).

Therefore, the DERMS OPF solution should be speed efficient whilst also having a high probability of finding the correct solution. AC Heuristic optimisation techniques provide adequate and fast solutions without guarantee of global optimality. This technique is used to heuristically and efficiently solve large combinatorial optimisation problems such as the one in TDI 2.0.

5.3.5 AC and DC Optimisation techniques

DC OPF is the name given to a linear approximated form of OPF that neglects the consideration of reactive power flows. It is typically used in transmission networks for the dispatch of real power and minimisation of generation costs, where the high X:R[9] ratio of the network means that the resistive component of equipment impedance can be neglected.

Reducing the non–linear power flow problem into a DC optimisation problem is practicable and operationally desirable in transmission networks, as it is less computationally complex. However, DC OPF is not suitable for distribution networks where the X:R ratio is much lower. Furthermore, in the DERMS reactive power services provision the tool must attempt to optimise the network in terms of Q & V. Hence, in this project, DC optimisation techniques will not be incorporated in the DERMS OPF solution.

5.4 Voltage Control methodology for DER

Historically in Great Britain DER are not generally required to operate in voltage control mode. This is because DERs with a capacity of less than 50MW are not required to comply with grid code requirements. Instead, they are generally required to operate in power factor control mode, which according to the Distribution Code should be maintained between 1.0 and 0.95 leading (i.e. absorbing VArs).

Figure 11 illustrates a reactive voltage droop compensation which could be applied at a utility bus bar. DER of type synchronous generator as well as non–synchronous could be given a predefined voltage control scheme as shown below to regulate their POC voltage. In addition, a dead–band could be inserted if necessary within the maximum and minimum voltage limit fixing the reactive power to be set to zero.

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[9] X:R Ratio is the ratio of the system reactance (X) to the system’s resistance (R).

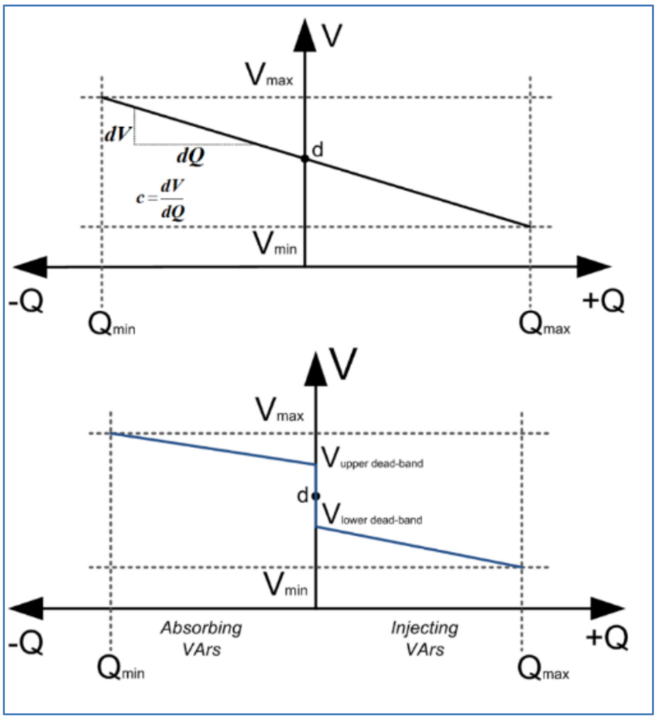

Figure 11 - The reactive capability diagram

Where:

V: Terminal POC Voltage

P: real power

Q: reactive power

c: Linear factor (gradient)

d: Point of inflection

DER must be able to accept a signal in order to change their mode of operation as well as a target value from voltage droop control to power factor (PF) operation. In this case, the reactive power is varied to regulate the power factor at a constant value. The DER could be instructed to operate at fixed power factor as illustrated in Figure 12.

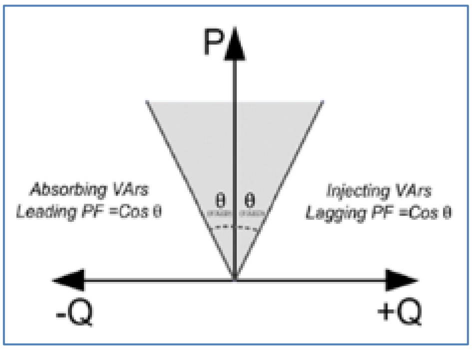

Figure 12 - Power Factor Regulation Mode.

However, in order to provide the reactive power services with the proposed functionality described in 3.2.2, the participating DER will be required to operate in voltage droop control. This control mode meets the functional requirements for providing the services with fast speed of response. DER acting in this mode will act to produce the set point voltage on its output terminals, by automatically varying the reactive power output according to the specified droop characteristic. When the services are not required, DER will be asked to operate in power factor operation mode.

The OPF component will derive the required voltage set points to be implemented by the DER when operating in the Service mode. Determination of which participating DER will provide the response will include consideration of the location, price and speed of response offered.

5.4.1 Real Power output control methodology for DER

The service mode operation of the DERMS active power services will output instructions to DER to vary their real power output according to the results of the OPF tool. As such the OPF will:

- Determine which DER have non–zero output and are available;
- Decide which DER will participate in the response, based on price, location, speed of response etc.; and
- Calculate the required curtailment per DER to achieve the requested response. The solution shall only use the remaining flexibility after any distribution network constraints have already been met.

The calculated requirement will be communicated to participating DER as a real power export set point.

6. High Level Architecture

6.1 Architecture Overview

Based on the design decisions detailed in Section 4 ICT Design Options and Section 5, the high level architecture for the TDI 2.0 solution is detailed in Figure 13 – To Be Architecture below. The diagram details the existing systems and integration interfaces (in blue) alongside the proposed new elements (in green/purple).

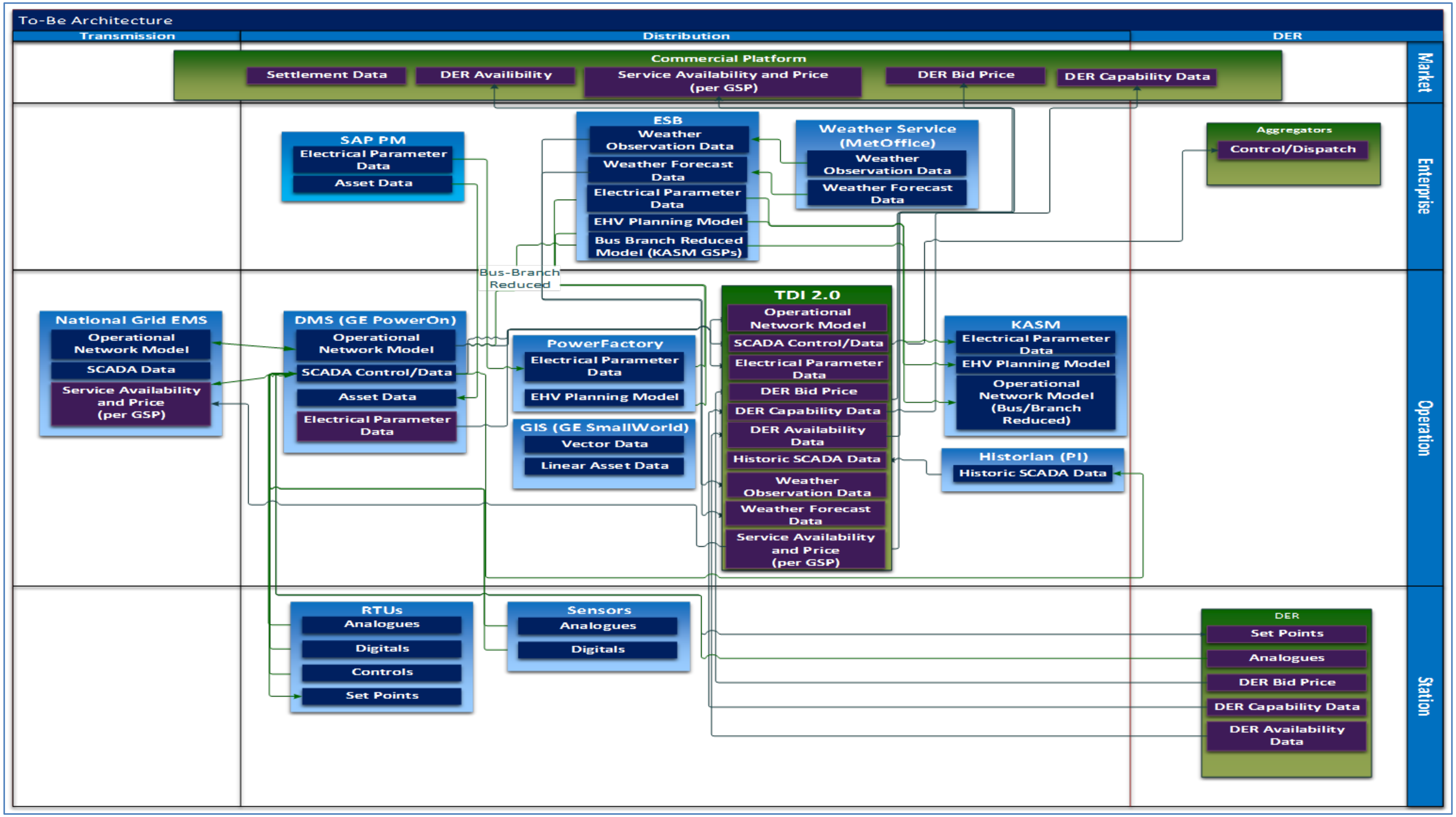

Figure 13 – To Be Architecture

6.1.1 Components (Logical Overview)

A brief description of each of the components is listed in the following sub–sections.

6.1.1.1 Distributed Energy Resource Management System (DERMS) software

The Distributed Energy Resource Management (DERM) software that performs Load Flow calculation, Forecasting, DER Control, and commercial functions to provide services requested by National Grid.

6.1.1.2 National Grid Energy Management System

National Grid's control system manages the electricity transmission network. UK Power Networks manages up to 132kV and National Grid manage all voltage levels at or above 132kV.

6.1.1.3 DER Control Systems

Each of the Distributed Energy Resources' systems which they use to control their plant (solar/wind farms, CHPs etc.)

6.1.1.4 PowerON Distribution Management System

PowerON is UK Power Networks' energy management system used to control the distribution network. This covers SCADA, resources, jobs, outages and customer calls.

6.1.1.5 DNO field equipment (e.g. RTU)

Remote Terminal Unit – devices which are wired into the substation plant and feed–back analogues (for example volts, amps, MW) and digitals (for example switch states, alarms) to PowerON.

6.1.1.6 PI Data Historian

Storage for historic SCADA analogues and digitals. Most SCADA data points have a 'tag' in PI which stores their values over time. PI uses a swinging door algorithm[10] to store data and so only stores a timestamp of change where the change is greater than or less than a given percentage of the current value. It then interpolates the missing values. This allows for lots of data to be stored in a small amount of space, compared to storing each point change.

6.1.1.7 Weather source

A premium subscription with the weather data source such as the Met Office. This includes all the standard values that can be obtained using the normal Data Point web service, but additional information such as solar strength, cloud coverage. This enables the DERM to predict the level of generation for a given DER.

6.1.1.8 Commercial and settlement application

The DERMS solution includes a commercial application which takes data from the DERMS control module and calculates the required payments to DER participants. DERMS will feed in the agreed price per MW/MVar, the amount of MW, MVar delivered etc. The settlement process will be defined in the detail commercial design.

6.2 Summary of Architecture

The TDI 2.0 solution design looks to re–use as much of existing systems and interfaces as possible. Where new systems or interfaces are required, the project will look to build components which are

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[10] A swinging door algorithm allows servers storing data to compress it by only storing what is determined to be meaningful data. This allows to improve disk space and reduces network traffic.

scalable and built in a re–usable manner. For a more detailed view of the architecture please refer to the architecture design document referenced in the Appendix F of the document.

7. Commercial High Level Design

7.1 Overall objectives and scope of the commercial design

This section covers the high level commercial design for the TDI 2.0 service. There is particular focus on the contract design and the contractual relationships between parties, from 12 months ahead of time through to minutes ahead. The section sets out the project's ambition for stakeholder engagement, including the Market Development Advisory Panel, and summarises the feedback received from potential participants to date.

Throughout the duration of the project, support will be provided by Imperial College and the University of Cambridge to inform the contractual and procurement approaches of the project and conduct a full cost benefit of the TDI 2.0 solution. The scope of this work with academic partners is set out here.

7.2 Service design

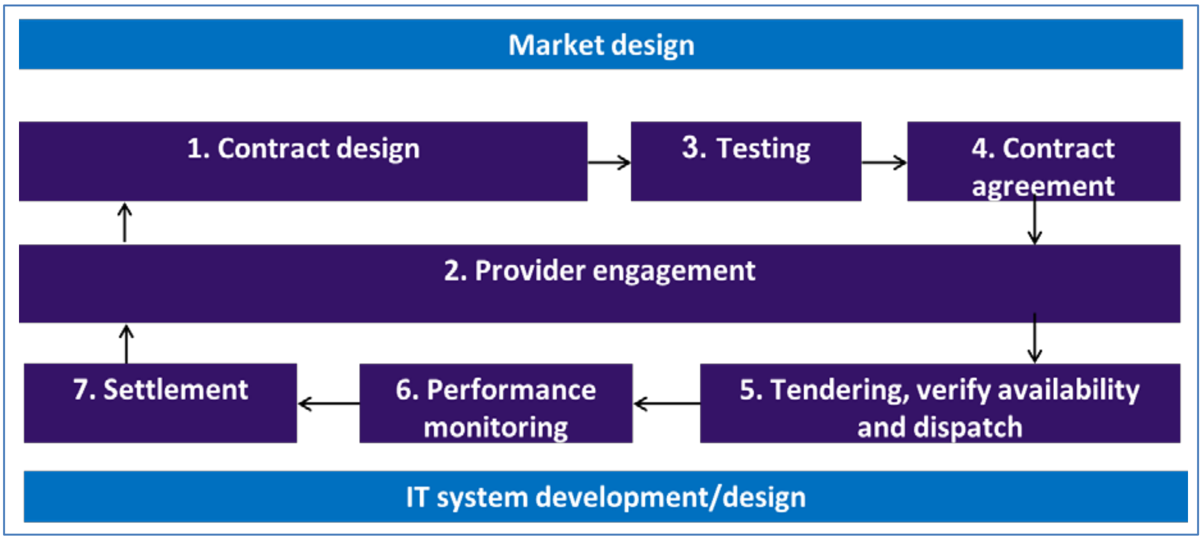

Figure 14 - Processes for designing commercial services

In developing new markets, consideration should be given to the contractual framework supporting the market or service. This will in turn capture the agreed process for, testing of assets to determine they meet technical requirements, how providers of the service will be assessed and dispatched, and how their performance will be monitored and remunerated. Throughout this lifecycle, engagement with participants and the industry is essential to inform the development of a new market.

Through the project, reactive power and active power for transmission constraint management will be offered by DER to National Grid via UK Power Networks, and arrangements for active power for distribution constraints will be held between DER and UK Power Networks. The high level roles and interactions between all parties are illustrated in Figure 15, including any existing contracts for Balancing Services DER may hold with National Grid.

The design of the market should also take into consideration the settlement process in accordance to the contractual arrangements. It should be able to identify when a service is being activated due to a constraint and differentiate the service amount delivered versus the natural response of the system.

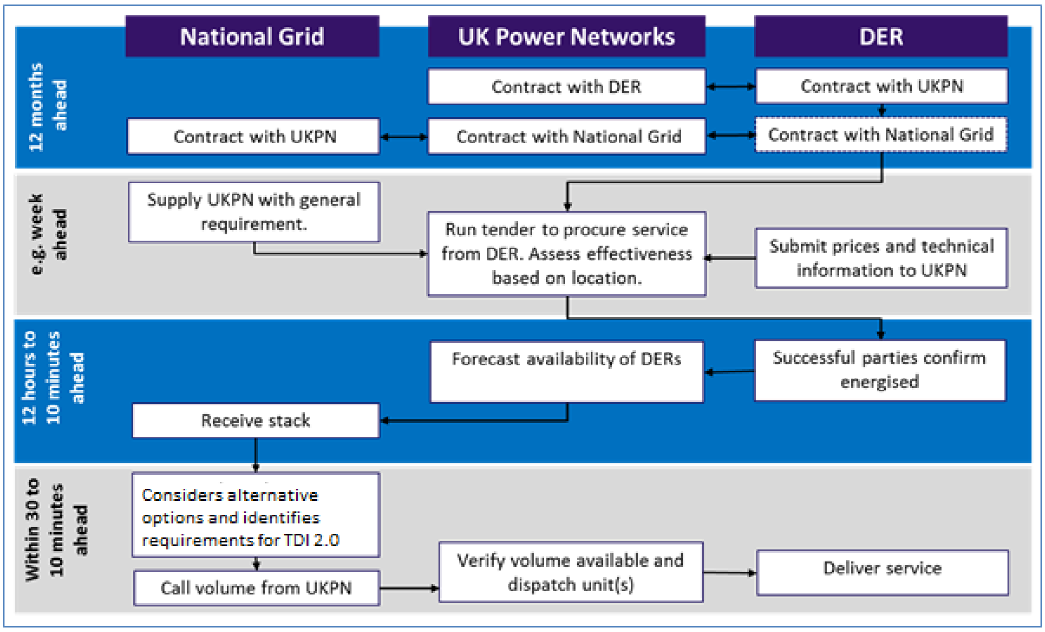

Figure 15 - Roles and interactions between parties

Following the design and implementation of contracts, tenders will be run closer to real time in order to procure services from DER. The timings of tenders will be driven by feedback from DER and how close to real time it is possible to determine system requirements. Throughout the project, the assessment criteria or value functions to be used during tenders to determine successful parties will be developed. These may include:

- Price offered for service delivery;
- Effectiveness of DER based on proximity to the GSP;
- Speed of response to changes to reactive power droop curves; and
- Availability during 'high value' periods or the ability to deliver a 24/7 service.

It is a fundamental principle that the approach used to identify the optimal solution will be transparent to UK Power Networks, National Grid and industry stakeholders. Initial feedback from DER reinforces the importance of clear signals to the market and transparency of requirements and decisions.

Via the DERMS platform, UK Power Networks will communicate with DER successful in the tender to forecast availability and send a confirmed stack of options to National Grid. When a requirement is identified by National Grid, all options will be considered and if the TDI 2.0 services are identified as the most economical solution, volume will be dispatched via UK Power Networks and the service delivered.

Careful consideration is required to determine the appropriate solution between longer term contracts that offer certainty to participants and shorter term tenders closer to real time that offer flexibility.

7.3 Contractual Design

To provide a framework for the delivery of services through this back to back arrangement (delivery of services coordinated by UK Power Networks), contracts will be required between DER and UK Power Networks, and between National Grid and UK Power Networks to capture the details of operational and commercial processes between parties. In addition, the contracts held between UK Power Networks and DER will capture bespoke details of each participant. The project aims to explore contracting with UK Power Networks as the primary route to market for DER. This contract relationship will not impact existing Balancing Services contracts between DER and National Grid and the project will keep open multiple routes to market, including contracting with National Grid for active and reactive power services.

Continued engagement with Balancing Services participants suggests that lengthy standard contract terms can represent a barrier to participation in services, streamlined contracts will be developed for the project in order to provide clarity on requirements and obligations and facilitate market entry. Additional good practice will be adopted to enable sharing of information between UK Power Networks and National Grid for operational purposes. For example, a previous trial to share an SO Balancing Service for transmission and distribution requirements highlighted the importance of contractual arrangements that permitted DERs' information to be shared between the SO and DNO for technical purposes.

Contracts principles will be developed by August 2017 and used to engage with and recruit DER throughout autumn 2017. It is the intention for signed contracts to be in place between DER and UK Power Networks by December 2017. The development of contracts will be aided by the agreeing heads of terms, which will be aligned with Future Role of the SO (FRSO) contract simplification, but may include:

- Service delivery – the method through which a dispatch signal will be sent from UK Power Networks and the expected response from the DER;
- Payment – the type of payment and frequency of payment made from one party to another;
- Service monitoring and testing – the method for determining delivery of the service on an ongoing basis, including any tolerances;
- Events of default and consequences – scenarios that would constitute under–performance and implications for the party delivering the services; and
- Warranty and indemnity – details protecting both parties from unforeseen events and limitations on liability.

7.4 Engagement and trial participation

7.4.1 Interaction with UK Power Networks connection agreements

It was noted during the DER participant workshop in May 2017 (further detail in Table 2 - Planned engagement with project participants) that the current connections process could provide a barrier for participating in the provision of DERMS services. Two possible issues were identified:

1. If the provision of TDI 2.0 services is dependent on updating existing connection agreements (e.g. to allow different technologies or operating profiles under the connection) then this could create a hurdle for DER participation;
2. For new connectees there may be a mismatch between the value they can provide through the TDI 2.0 services and the position they can achieve in the connection queue, which could result in potentially valuable assets being unable to participate.

The connection arrangements are under review to determine the materiality of these risks, and to identify possible solutions. To remove barriers to participation, the intention is to adapt agreements in line with the development of the project to reflect the operational envelopes required by participants, under the assumption that any changes continue to protect the network and customers.

As part of the design of the supporting business process required to coordinate the TDI 2.0 services, the connection queue will be reviewed whilst assuring fair treatment to all new connectees participating or not in the market.

7.4.2 Value stacking

Feedback from attendees of the DER Participant Workshop on 9 May indicated that the ability to 'stack' revenue streams (that is, deliver multiple services to multiple parties) was an important consideration in developing new markets. Value stacking not only potentially offers DER to maximise their revenue opportunities, it is key to growing participation in new services as, faced with the choice of participation in only one service, DER may pursue a more established or more lucrative opportunity if the new service is not perceived as sufficiently attractive. With this in mind, there are two key activities that the project will need to deliver:

- Take a balanced approach to ensuring that the reactive and active markets created through the project provide sufficient assurance for the SO and DNO that participants will deliver the required action, whilst managing the requirement for firm procurement to allow DERs to participate in other services; and
- Review the terms of the other SO services and the interaction with those services to identify areas where exclusivity requirements could be relaxed. Currently it is possible for DER to hold contracts for and deliver multiple services to parties providing that the delivery of one service does not impact the ability to provide the other contracted services. For example, it is possible for a DER to offer Short Term Operating Reserve (STOR) during specified availability windows and deliver Firm Frequency Response (FFR) outside of these windows, but not both services simultaneously from the same volume. This is due to the SO's requirement to procure services on a firm basis i.e. there is an understanding that services providers will be available to deliver when required. This allows the SO to procure specific volumes based on identified requirements.

If DER wish to make themselves available for multiple services simultaneously, one option is for the SO to procure services on a non–firm basis. In this case, however, there may be the need for the SO and DNO to procure additional volume to cover the risk of non–delivery. Alternatively, a commercial aggregator could tender for services, meeting the firm obligation through the management of its portfolio. In order to understand how DER or aggregators could offer multiple services simultaneously, it will be necessary to understand how frequently conflicts of service may occur, the implications and how this could be managed. Clear price signals are needed to reflect the value of different services to National Grid and UK Power Networks.

In the scenario where SO services are being delivered by parties connected behind a distribution constraint, in addition to the interactions between commercial services, it is important to consider the impact of any non–commercial actions for constraint management taken by the DNO. If market–based ANM schemes are introduced, this is expected to provide a mechanism to facilitate the provision of SO services by DER on constrained distribution networks. In the meantime interim approaches may be needed. In conjunction with learning from groups such as the ENA's TSO-DSO project, analysis is again required to understand the frequency of conflicts and potential solutions. Within this document, Section 9.2.1.1 further addresses the potential for functional and ICT conflicts where SO services are procured from parties connected to the distribution network. As well as explaning the concept of conflicts, the section expands on consequences and possible mitigation. The contractual and commercial conflicts and mitigations will be explored alongside the technical conflicts throughout the project.

7.5 Working with the academic partners

The scope of research to be carried out by Imperial College (points 1 and 2) and the University of Cambridge (points 3 and 4) is divided into four areas:

1. Modelling to determine the most cost optimal solution of commercial contracts (of different durations) taking into account system condition driven changes;

2. Evaluate the commercial synergies between distribution and transmission systems and understand the value of reactive power to the DSO;
3. Identification of best practice conceptual market applicable to DERs; and
4. A full cost benefit assessment of the project and the proposed solution.

For details please see Appendix D. (Due to confidential reasons this appendix is not made available in the public domain)

7.6 DER Provider Sign–Up

7.6.1 DER Provider Engagement Strategy

In order to maximise the effectiveness of engagement with DER and deliver confidence in new market solutions, National Grid and UK Power Networks have adopted a joint approach to stakeholder engagement. The level of engagement required will differ between DER participating in the project and DER (or other industry stakeholders) that simply wish to be kept informed of developments. To engage these parties, a variety of channels will be used to communicate and consult, including webinars, workshops, one to one discussions and electronic (email/website) updates. Table 2 below details engagement activities.

Planned Communication	Who	Channel	Date
DER participant workshop Participants will have the opportunity to share their general feedback, as well as being asked specific technical and commercial questions	Cross–section of aggregators and directly connected customers who expressed interest in the project. 17 attendees to enable open discussion.	Workshop	9 May 2017
Webinar **Communicate latest updates to industry and offer opportunity to ask questions and provide input**	All interested DERs (and other parties)	Webinar (and slides published on the project's website)	June/July
One–to–one engagement **Discussions around service provision and bespoke capabilities/requirements of participants (which may be sensitive/confidential)**	DER participants in the South East coast area	Face to face	Summer/Autumn 2017

Table 2 - Planned engagement with project participants

7.6.2 DER trial participation requirements

The DER providing reactive power service must be capable of continuous changes to the reactive power supplied to the distribution system in order to contribute to voltage control. The reactive power is varied to regulate the voltage within limits. Section 5.4 describes how DER operating in voltage droop control would be able to achieve fast changes to their reactive power output based on changed in the voltage at the point of connection.

Increases in voltage above the target should cause the site to absorb reactive power (inductive operation) and reduction in voltage causes the plant to inject reactive power (capacitive operation). As illustrated in Figure 16, the reactive power transfer in either direction is proportional to the difference between the actual voltage and the desired voltage.

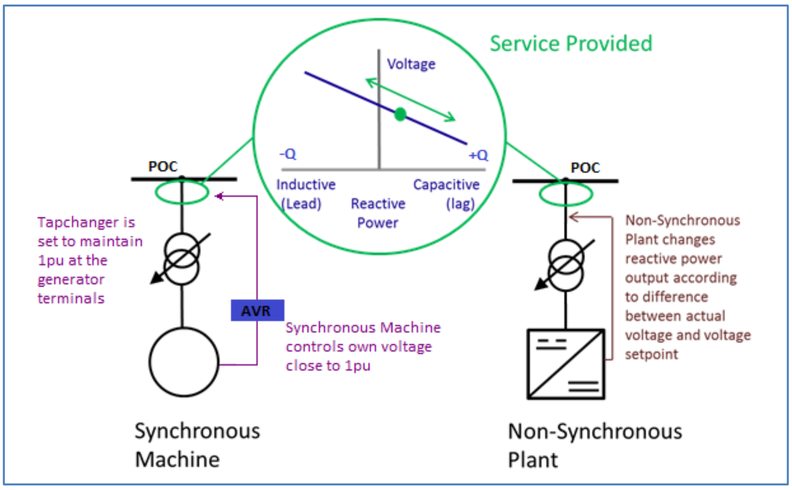

Figure 16 - Example of DERs providing reactive power service

7.6.1 High level trial requirements

A summary of the proposed high–level requirements which must be met by the DER participants is presented in 5.4. The concept of voltage droop control and other operating characteristic are outlined in the DER Technical Operating Characteristics (Reference [1]) document found on the project's website[11].

Requirements	Plant Capacity	
	Larger than or Equal to 50MW	Smaller than 50MW
Converters/Inverters to provide continual voltage droop control within ≤10s for dynamic voltage control at POC.	✓	✓
Continual active power control (≥1000kW/min ramp–rates) at POC.	✓	✓
Fault ride through capability of DER to remain connected for a total fault clearance time of up to 140ms.	✓	Under investigation
Frequency control for large DERs or DGs which impact national frequency limits.	✓	Under investigation

Table 3 - DER requirements based on installed capacity

7.6.2 DER Feedback

DER participants who expressed an interest in the project at the stage of the bid were invited to attend a technical and commercial workshop on 9 May 2017. This workshop offered an opportunity to communicate initial technical and commercial developments and seek the views of DER to shape the development of the project.

Three themes emerged from the feedback received from 13 of the 17 DER participants:

1. Attendees appreciated the opportunity to engage early in project
2. Parties need more clarity on what National Grid and UK Power Networks want in order to understand the opportunity
3. It was recognised that there is still work to be done and questions to be explored

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[11] http://www2.nationalgrid.com/UK/Our-company/Innovation/NIC/Power-Potential/?LangType=2057

Discussion highlighted the topics of importance to DER and centred around:

- How DER could create an investment case between reactive power, constraint management and wider system services and the role of National Grid and UK Power Networks in this
- The polarised views between parties seeking longer term contracts to deliver certainty and the preference for shorter term markets that offer greater flexibility
- The compatibility of reactive power and other Balancing Services/connection agreements, particularly if parties have existing contracts
- The importance of a coherent approach between DERMS and the Regional Development Programme (RDP) in order to maximise the benefit of the trial

7.7 Advisory Panel

A Market Development Advisory Panel will be established, with stakeholder representatives from National Grid, UK Power Networks, Ofgem, DER, aggregators, Imperial College and the University of Cambridge. The purpose of the panel will be to ensure a transparent and consistent approach throughout the development of new services, providing guidance on ways to reduce barriers to entry, maximise participation in new markets and ensure there are no unintended impacts on other services or stakeholders. The panel will provide a valuable opportunity to maximise engagement with potential project participants throughout the duration of the project in order to shape the development of the new services being created.

8. High Level Business Processes

Introduction and Problem → Services Definition → Architecture Design → Commercial Considerations → **High Level Business Processes** → Synergies and Conflicts → Summary

This section aims to provide a high level description of how UK Power Networks and National Grid business processes will be affected by the introduction of the TDI 2.0 services.

Throughout the project UK Power Networks and National Grid will continuously develop and implement the overall business change strategy that will ensure smooth transition from project design, build and testing into trials and into business as usual as well as encompassing business readiness, process mapping, communications, organisational changes and training. More details on these will follow in subsequent project reports.

The rest of this section focuses on the high level processes that will operate the solution, including an assessment on the business process impacted and a high level view on the existing process and the expected transition required.

8.1 High level impact of TDI 2.0 on National Grid

Within National Grid there are nine value streams that are involved in transmission voltage and frequency management services at different points of the timeline. Should TDI 2.0 be implemented these are the departments that may be affected as shown in Figure 17 .

Each of the departments have responsibilities and processes that they follow in their time sphere. Changes may be necessary to accommodate the management of reactive and active power with DNOs.

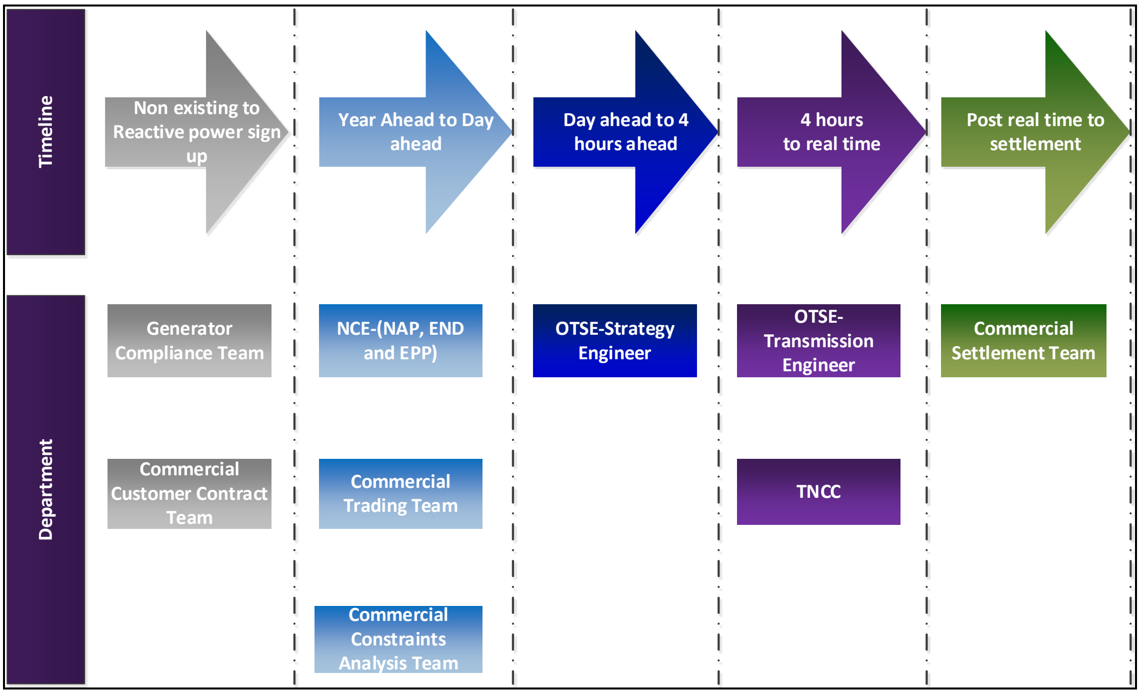


Figure 17 - Departments involved in existing reactive and active power management within National Grid.

Generator Compliance team is responsible for confirming the active and reactive power capability of generators that wish to connect to the GB system. **Commercial Customer Contract** Managers liaise with customers in the process of signing Mandatory Services Agreements (MSA) where necessary. This agreement gives effect to the necessary clauses in the Connection and Use of System Code (CUSC) and

Grid Code that define a generator's obligation and payment for the services. **Commercial Constraints** Analysts are responsible for contracting services based on requirements that are defined by the Network Access Planners. **Commercial Traders** are responsible for trading units that provide reactive and active power services based on requirements set by Network Access Planning (NAP) team. **Network Access** staff are responsible for planning and maintaining an up–to–date record of the generator capabilities. **Control Room Engineers** finalise the transmission system operating plan and despatch reactive power from synchronised generation once the Transmission Network Control Centre (TNCC) has used available static equipment. **Zonal Managers** at the TNCC are responsible for maintaining and monitoring all reactive power reserve levels within their sphere of operation. **Commercial Settlements** work with ELEXON in settling any imbalance post real time.

It is anticipated that the main impact will be on Network Access Planning, Electricity Network Control Centre and the Transmission Network Control Centre as they will have significant responsibilities within the operation of TDI 2.0. National Grid's high level process will include procuring for active and reactive power services and ensuring services are received at GSPs as shown in Appendix E.

8.2 High level impact of TDI 2.0 on UK Power Networks

It was identified that new processes (or business teams) within UK Power Networks would be required to accommodate the service provision. Therefore, it was necessary to develop an entirely new business process and DER Scheduling team for delivering the TDI 2.0 services.

The developed process is described in Appendix E. The process is structured in three phases which will be involved in operating the solution. These will be largely automated with manual intervention described in the support process, and general housekeeping processes. The identified high–level process will be amended and augmented as the TDI 2.0 project progresses and the outcome of this detail design will be presented in SDRC 9.2 Stage Gate 1 – Commercial and Detailed Technical Design.

At this stage, the main affected teams within UK Power Networks are Network Control, Outage Planning, and Information Services. Of these, Network Control and Outage Planning will have significant active roles within the overall support process for TDI 2.0, and Information Services will have the responsibility of maintaining the operational status of the software developed for the TDI 2.0 service. The impact on other teams such as Major Connections, Income Pricing, Infrastructure Planning and Legal will be defined in the detail design.

The new team, the DER Scheduling team, will be responsible for the operation of the TDI 2.0 services within UK Power Networks. They will have operational ownership of the DERMS platform, undertake all engagement with external stakeholders, particularly National Grid and the DER clients, undertake all advance scheduling of DER for the service, liaise with internal stakeholders regarding security of supply issues and monitor the service response. As the scheduling DER for the service will require commercial knowledge, it is anticipated that the typical member of this team will have commercial analysis skills as well as control room network management expertise.

8.3 High level Business Processes

The high level service interaction between National Grid and UK Power Networks is shown in Figure 18 below:

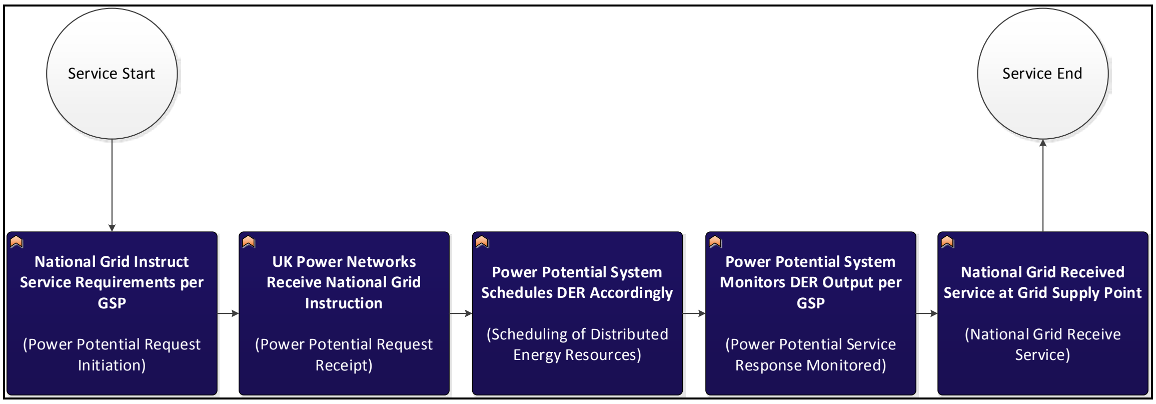


Figure 18 - TDI 2.0 Interaction

National Grid will be responsible for calling on the services through UK Power Networks. UK Power Networks will act as technical coordinator responsible for managing the despatch of the services in real time. Additionally, UK Power Networks will be in charge of sourcing and establishing DER capability for reactive and active power services on behalf of National Grid as well as managing the despatch of the DER in real time. Detailed responsibilities are shown in Appendix E, which shows the process that will operate TDI 2.0 service.

9. Review of anticipated synergies and conflicts

Introduction and Problem → Services Definition → Architecture Design → Commercial Considerations → High Level Business Processes → **Synergies and Conflicts** → Summary

The project has reviewed and structured the high level design of technical, commercial and business processes required to support the services requirements. In the development of the detail design and subsequent build and testing phases, several synergies and conflicts will materialise. The scope of this section is to highlight the anticipated synergies and conflicts identified at this stage which will be tracked during the lifetime of the project. Some of these have already informed our design decisions and have been highlighted in other sections of this document.

Based on their impact, synergies and conflicts can be categorised as:

- Functional: A synergy or conflict that will have an impact on the functionality (services) design on the project
- Architecture: A synergy or conflict which can have an impact on the technical design of the solution to achieve the functionality required.

9.1 Synergies

The main anticipated synergies identified at this design stage are

- Regional Development Programmes
- Kent Active System Management (KASM)

9.1.1 Regional Development Programmes (RDPs)

As a result of the recent and future changes to both companies' networks, new ways of working between the TSO and DNOs will be needed for the GB system. This new "whole system" industry model will be required to enable the optimisation of planning and operation of the system across transmission and distribution. One of the key goals of this enhanced collaboration is to facilitate new interactions between all market participants including DER and aggregators. The approach taken to define how SOs and DNOs will work together in the future seeks to drive continued progress through regional programmes focussed on solving today's issues whilst jointly co–creating the new "whole system" industry model.

The Regional Development Programmes (RDPs) were set up to provide detailed analysis of areas of the network which have large amounts of DER and known transmission network challenges in accommodating that DER capacity. The objectives of the RDPs are:

- Investigate "whole system" investment and operability constraints;
- Co–design solutions working jointly across transmission/distribution and wider participants;
- Trial approaches that can be achieved in the short to medium term;
- Design by doing – delivering benefits and DER connections capacity; and
- Complement and support existing innovation projects.

The South East Coast network, which has the same focus area as the TDI 2.0 project, has been selected as one of the regions to develop the RDPs. This is due to the same voltage transmission constraints that drives the TDI 2.0 project and have led to limitation of the existing transmission capacity for connection of future DER customers. As adequate capacity allocation and fast connection processes are key requirements for DER customers wishing to connect in the UK Power Networks area, both SO and DNO are partnering to find short terms solutions to meet DER needs and release DER connection capacity in this constrained area.

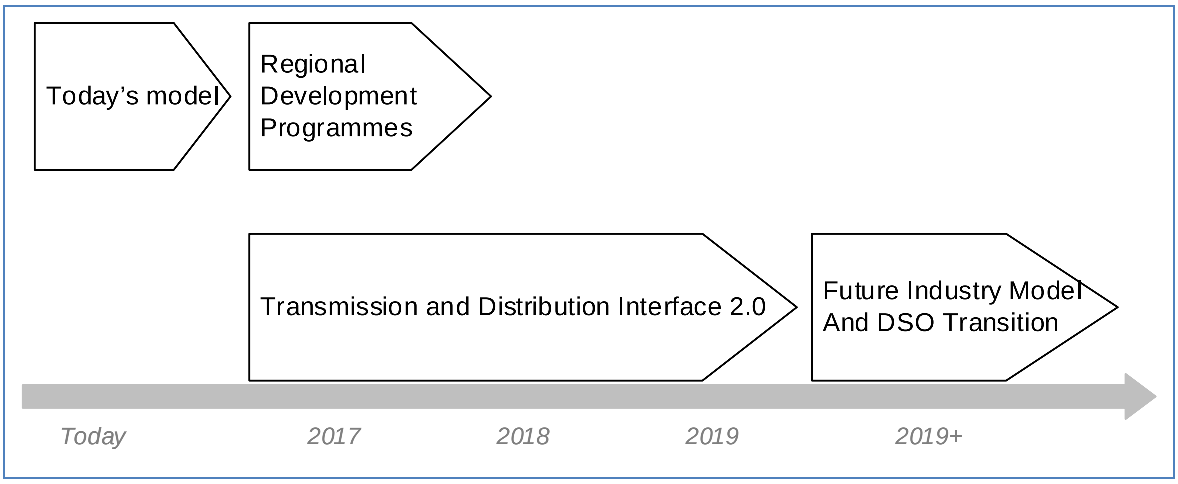


Figure 19 - RDP and TDI 2.0 timelines

Figure 19 summarises the timeline of the RDP and TDI 2.0 projects. The main synergy between the two is to find short term (RDP) and long term solutions (TDI 2.0) solutions to operational challenges in the area. These solutions need to be designed such that they complement each other and build towards the future industry model and DSO transition.

Since late 2016, National Grid and UK Power Networks have been actively working together to unlock further connection capacity in the South East Coast. This includes finding commercial and technical solutions that can be structured during 2017 and build towards the TDI 2.0 technical and commercial aspects.

Significant efforts have been deployed to improve the dynamic modelling of the South East Coast network to include the transmission and distribution data. This dynamic model has helped to understand the true impact of the double circuit fault between Canterbury and Kemsley which is the main driver behind the capacity limit. As part of the RDPs, both companies engaged in information gathering and sharing activities to improve the model. This model was then used by the TDI 2.0 team to formulate the dynamic response needed from DER as described in section 3.2.

Other key outcomes from the RDPs will be the arrangement of a commercial framework for active power management to enable further DER connection capacity in the area where DER will be financially compensated for transmission constraints. New DER connections will be subject to a "Flexible Connections" scheme where their output can be constrained depending on rules of access and system's needs. This commercial framework will be a learning point used to formulate the detail design of the TDI 2.0 commercial structure and how these two arrangements can be articulated to customers preventing any conflicting service frameworks.

9.1.2 Kent Active System Management (KASM)

The Kent Active System Management (KASM) project aims to carry out a range of technical innovation trials to demonstrate more advanced operations and planning techniques for the 132kV and 33kV network in East Kent. The TDI 2.0 and the KASM trial areas overlap on Canterbury, Sellindge and Ninfield GSPs and therefore provides a great opportunity for learning outcomes to be shared. By using some of the functionality developed in the KASM project, we will be able to avoid duplications in integration needs. The key learnings can be summarised as follows:

Requirements from functionality (TDI 2.0 services)	Learnings from KASM	Application in TDI 2.0
The services are to be instructed from National Grid to UK Power Networks.	The KASM project has deployed an ICCP link that connects UK Power Networks' and National Grid's control rooms to make real–time data requirements exchanges possible	The ICCP link developed by KASM will be used to instruct the services from National Grid to UK Power Networks.
In order to accurately calculate the service availability and dispatch, visibility of the transmission network of the South coast as well as SCADA data is required.	KASM has developed a process such that the network connectivity model of the South coast transmission system is visible in UK Power Networks' PowerOn. This includes: • Network topology and topology changes; and • SCADA data	TDI 2.0 will use the regional power connectivity model (transmission and distribution) provided by the KASM project in the power flow analysis and OPF calculations.

Table 4 - KASM Learnings

A key learning to highlight is the ICCP link developed by KASM which has enabled the UK Power Networks' control room to have real–time visibility of the National Grid's South East network topology and SCADA measurements.

TDI 2.0 service requirements particularly for avoiding a low voltage excursion in the system, will require the most up–to–date regional network model and SCADA measurements in order to provide the an optimal response from the distribution network and DER. Without the ICCP link in place, the load flow and optimal power flow functions described in Section 5.3 would not be able to fully assess the whole system implication to a particular service, its availability and utilisation.

The ICCP link has proven to be one of the crucial learning points and synergies during the high level architecture design as it allows the project to meet the functional requirements without the need for significant additional investment. During the detail design phase, the sizing of the ICCP link will be analysed to identify if changes or enhancements to the infrastructure are required to meet both KASM and TDI 2.0 project requirements.

9.2 Conflicts

The main anticipated conflict identified at this design stage is related to service dispatch conflict in the area which are presented in this section.

9.2.1 Service dispatch conflicts in the area

Currently there are services such as Enhanced Frequency Response being procured by the SO directly to DER connected in the distribution network. These directly contracted services are not coordinated by the DNO, which could lead to possible conflicting actions. This section describes the concept of service conflicts, consequences and next steps to mitigate them.

9.2.1.1 Service conflicts – Overview

As many DNOs are accommodating increasing number of DER connected in their networks, they have been looking into ways to manage their system optimally. This has led to a widespread deployment of

Active Network Management (ANM) schemes across their networks to manage distribution constraints. By limiting the output of DER at certain times, ANM allows increasing the connection capacity beyond that which could connect using traditional planning assumptions. The active power service from TDI 2.0 will build from the basis of ANM to solve distribution constraints and then offer additional flexibility upstream to National Grid. The DERMS software can be subject to the same service conflicts as an ANM which are described in this section.

Industry stakeholders, particularly through the Energy Networks Association (ENA) TSO–DSO working groups, have identified the potential for ANM schemes to, at times, conflict with embedded SO services by negating service output. SO services embedded in the DNO network may be impacted by ANMs either:

- For services which increment: if the ANM is active at the time (or doesn’t have sufficient headroom) then the service effect will be negated seconds later following ANM action to curtail alternative generation.
- For services which decrement: if the ANM is active at the time the controlled DER will “fill in” the space made by the service with the extent of the fill in being determined by the volume of other DG/DER being curtailed prior to the decrement service.

An illustrative example of an incremental service conflict is given in Figure 20 where an ANM is actively curtailing distributed generation to 70MW in order to control the flow on a DNO circuit within its rating limit of 50MW. In this example, there is an embedded SO service, Short Term Operating Reserve (STOR), within the ANM Zone not itself under ANM or DERMS control. Should the STOR service be called upon by the SO to generate 20MW, seconds later the service’s output could potentially be nullified by the ANM pulling back an equal amount of DER output to return the circuit to within its rating.

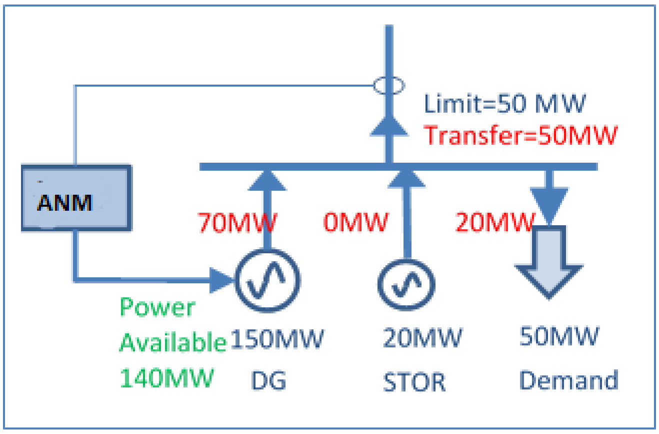


Figure 20 - Example embedded incremental service conflict

An illustrative example of a decremental service conflict is given in Figure 21 below where an ANM is actively curtailing distributed generation to 70MW to control the flow on a DNO circuit with a rating limit of 50MW. In this example, there is an embedded SO service, Enhanced Frequency Response (EFR), within the ANM Zone not itself under ANM or DERMS control. Should the EFR service automatically absorb power in response to a rise in system frequency as per its service requirement, the ANM would detect the spare capacity and seconds later the service’s output could be nullified by the ANM releasing an equal amount of previously curtailed DER output.

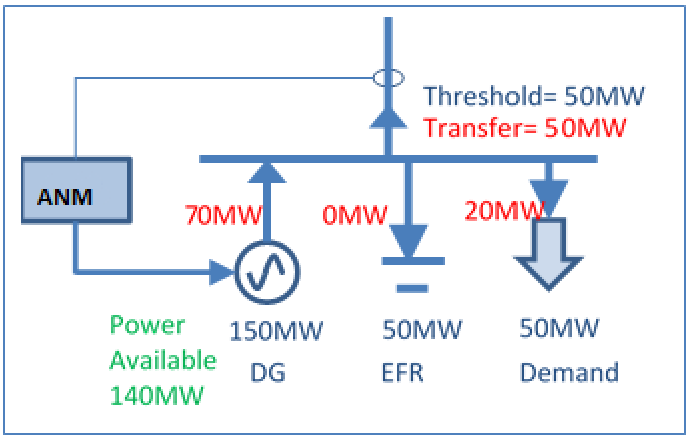


Figure 21 - Example embedded decremental service conflict

9.2.1.2 What are the consequences of the problem?

It is expected for the SO to continue to procure ancillary and balancing services from providers embedded in the distribution network. Furthermore, ANM type of control systems are expected to be deployed in other areas of the system. Thus, the risk of conflicting actions can be expected to grow. The consequences to the system's operation without mitigation would be, at times when ANMs are active, that services do not deliver the expected net output either requiring additional services to be run at extra cost.

In the particular case for TDI 2.0, the risk of service conflicts can still materialise as some SO service providers are connected in the trial area. All TDI 2.0 services procured by National Grid will be coordinated by the DERMS software to avoid conflict between those. However design allowances have to be made to include the detection of other services being procured in the area and their possible conflict resolution.

9.2.1.3 Key next steps and mitigation

On the requirements specified for the DERMS software provider, a provision has been made for the software to be able to process data containing details of other services being procured in the area and be able to actively manage to conflict with a pre–determined set of rules. These rules will be defined in the detail design stage.

Furthermore, the ENA TSO–DSO working group will continue to work in understanding service conflicts and how these could be addressed in planning timescales, short–term planning timescales and real–time.

As industry collaborates, this potential conflict can become a synergy. This enabling function will be providing means to test approaches to managing service conflicts that should support ENA work goals and further SO/DNO collaboration.

Beyond the above, future work in this area would be to identify methods for ANM or DERMS type of control systems to, at times, fully accommodate SO embedded services and to identify when this would be an appropriate solution. Learning from the TDI 2.0 technical coordination from the DNO will help inform future design decisions.

10. Summary

Introduction and Problem → Services Definition → Architecture Design → Commercial Considerations → High Level Business Processes → Synergies and Conflicts → **Summary**

In this report, the high–level design of the project is summarised and presented. It focused firstly on introducing the key functionalities required by the project in terms of the TDI 2.0 services and their requirements. This was followed by the technical high–level design comprised of design options to meet the services description. The technical design was complemented by a review of the commercial framework and business processes that will operate the solution.

A summary of the evidence provided per criteria is summarised in the following sub–sections.

10.1 Functional design document

The TDI 2.0 project will facilitate the following services:

- Dynamic Voltage Control:
  - Dynamic voltage service (Low Voltage).
  - Dynamic voltage service (High Voltage, previously named steady–state voltage service).
- Balancing service using re–dispatching of MWs.

The dynamic voltage control are Reactive Power Services and constraint management service is an Active Power Service.

The principles on how these services will work and similarities between wind farm voltage control were summarised in Section 3. The functional design was structured in the form of flow chart diagrams which describe the interactions between National Grid, UK Power Networks and DER to deliver each service.

With the key functionalities in mind, the high–level requirements for the DERM solution were summarised. The DERMS will be the software which will perform market and technical coordination to enable the services to be procured from DER by National Grid via UK Power Networks.

This high level functional design is the basis of the next sections where the high level design is described to achieve the service requirements.

10.2 Alternative design options considered and selection criteria

Sections 4 and 5 explore the different options to achieve the functionality previously set out in Section 3. Section 4 focuses on ICT Design, which consider the options for the project's integration with existing infrastructure of UK Power Networks and National Grid. The key option criteria used for the ICT design options are:

- Time: achieve the project delivery timescales;
- Cost: deliver the flexibility within the project's budget;
- Scalability: the design should be scalable such that is able to expand to other DNO regions and to include new smart grid functions; and
- Future proof: the design should be in line with the relevant UK Power Networks' strategies.

The ICT design options considered include:

- Network connectivity model;
- Real time SCADA data;

- DER control interface;
- Infrastructure hosting; and
- Communication interface topology.

On the power systems design options, the assessment was focused on the required features to be included in the DERMS to achieve the service requirements. This section focused on:

- Forecasting;
- Power flow and state estimation;
- Optimal power flow; and
- DER reactive and active power control.

10.3 High level design specification

A proposed high level architecture is introduced in Section 6 and corresponding Appendix F.

The ICT architecture for DERMS integrates multiple functions and solutions together. The approach to designing this architecture is to apply the outcomes of the design options previously described in section 4.1.2 (Design Considerations) in line with the design principles. The design options resulted in a set of architectural decisions which have determined the high level architecture.

Section 6 describes the architecture's main characteristics such as interfaces, components, topology, and security.

As the project seeks to create market arrangements for the services, this report has included a high level view of the commercial framework and learnings to date based on interactions with DER customers. This was presented in Section 7.

10.4 High level business processes

The DERMS solution will require business processes that will enable the operation of the market and the services. Section 8 provides an overview of the high level business processes that will be required to operate the solution. It provides a summary of the affected processes in National Grid and the introduction of new processes in UK Power Networks to achieve this service coordination which is not currently done by the DNO. This review will be covered in more detail in the following SDRC.

10.5 Review of anticipated synergies and conflicts

Finally, in the definition of this high level technical architecture, synergies and conflicts were identified such that we can leverage synergies and mitigate against conflicts.

Key synergies include the Regional Development Programmes between National Grid and UK Power Networks where short–term solutions to operational challenges in the South East have led to increased cooperation which in turn will lead to access to more connecting customers. Another synergy is the KASM project, currently in its final year, which is deploying an ICT Contingency Analysis tool in an overlapping area with TDI 2.0. Key learnings from KASM have been used to inform the design decisions and avoid duplications where possible.

An anticipated conflict has been identified as conflict of services between TDI 2.0 and other National Grid services that are not coordinated by the DERMS. This conflict of service is being studied by the ENA TSO/DSO working group and will inform the best practice in service coordination. This project will draw on the best practice developed in designing the solution.

Appendix A – Low Voltage Use Case

Sensitivity Calculation

The Sensitivity Calculation functionality for Low Voltage Use Case is demonstrated in Figure 22.

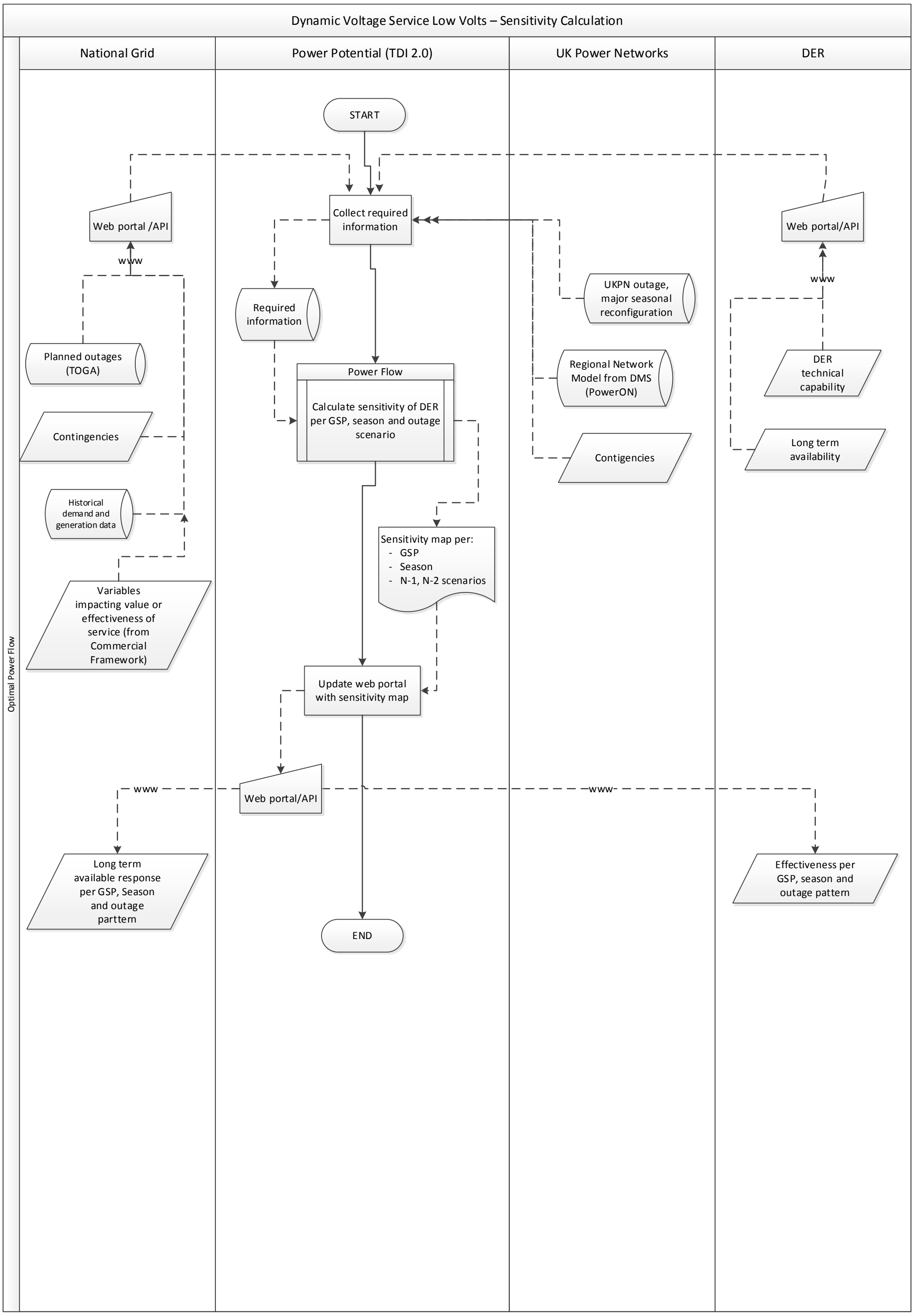


Figure 22 – Sensitivity Calculation – Low Voltage Use Case.

Day Ahead

The Day Ahead functionality for Low Voltage Use Case is demonstrated in Figure 23:

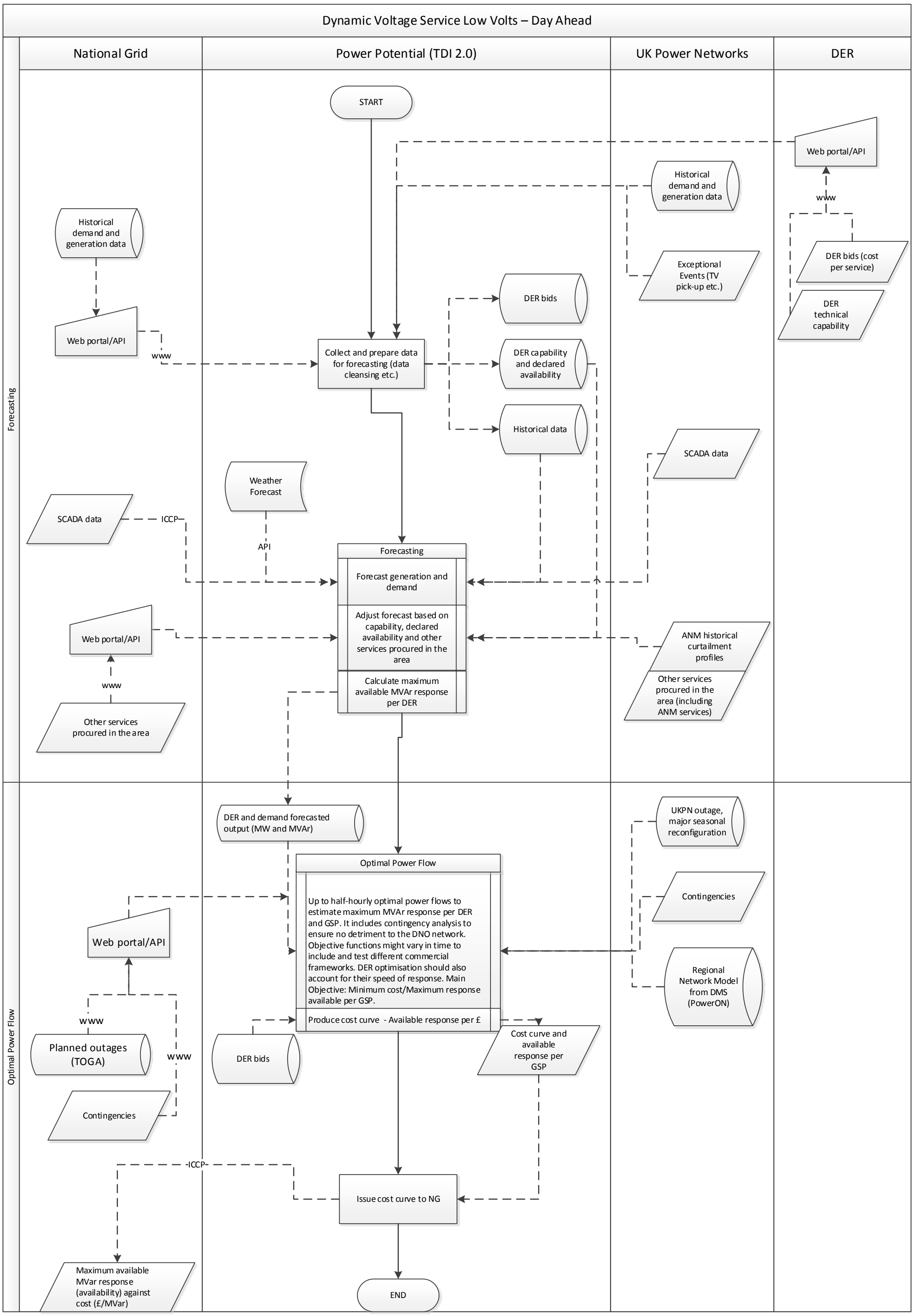


Figure 23 – Day Ahead – Low Voltage Use Case.

Service Mode (real–time)

The Service Mode functionality for Low Voltage Use Case is demonstrated in Figure 24:

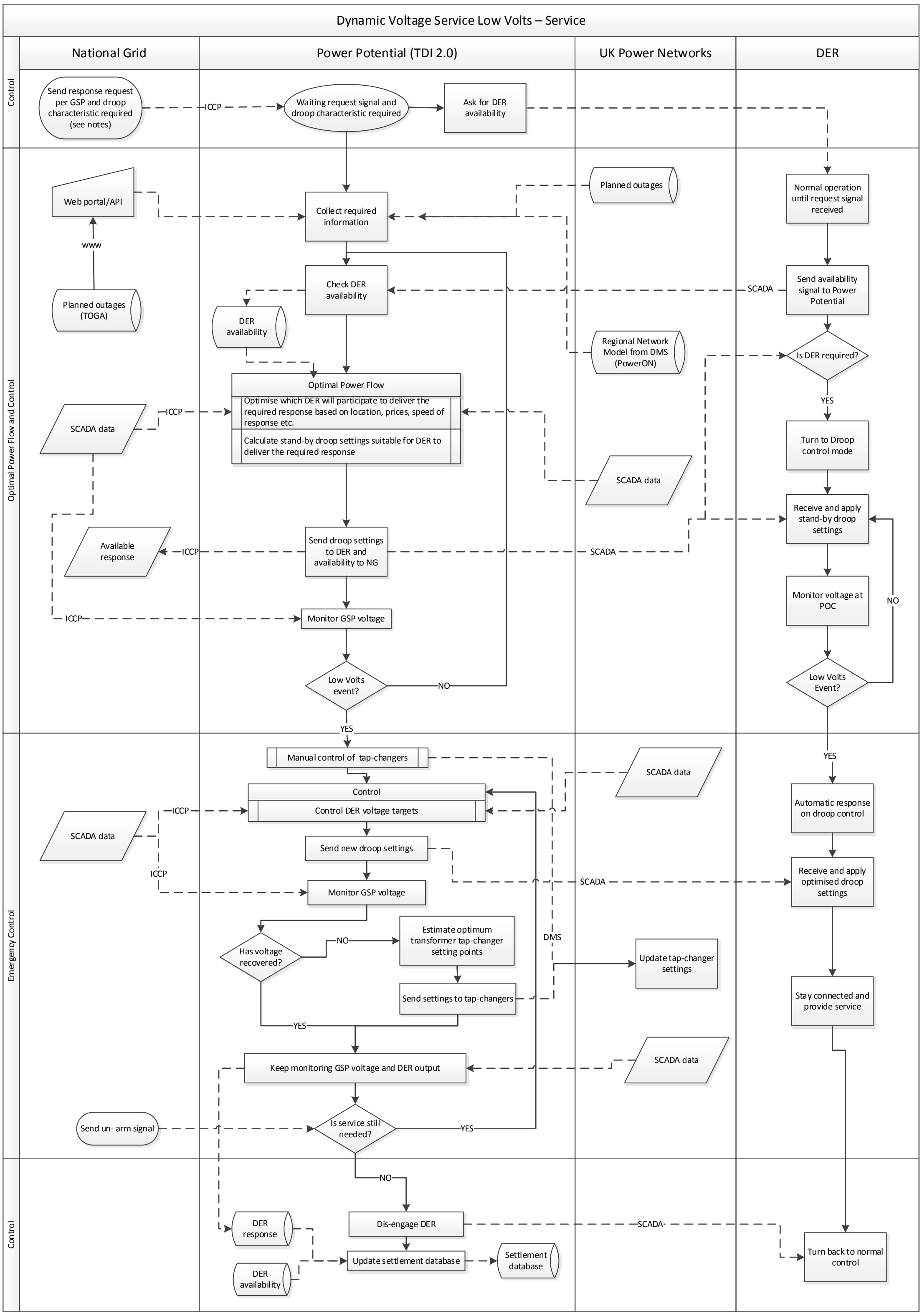


Figure 24 – Service Mode – Low Voltage Use Case.

Appendix B – High Voltage Use Case

Sensitivity Calculation

The Sensitivity Calculation functionality for High Voltage Use Case is demonstrated in Figure 25:

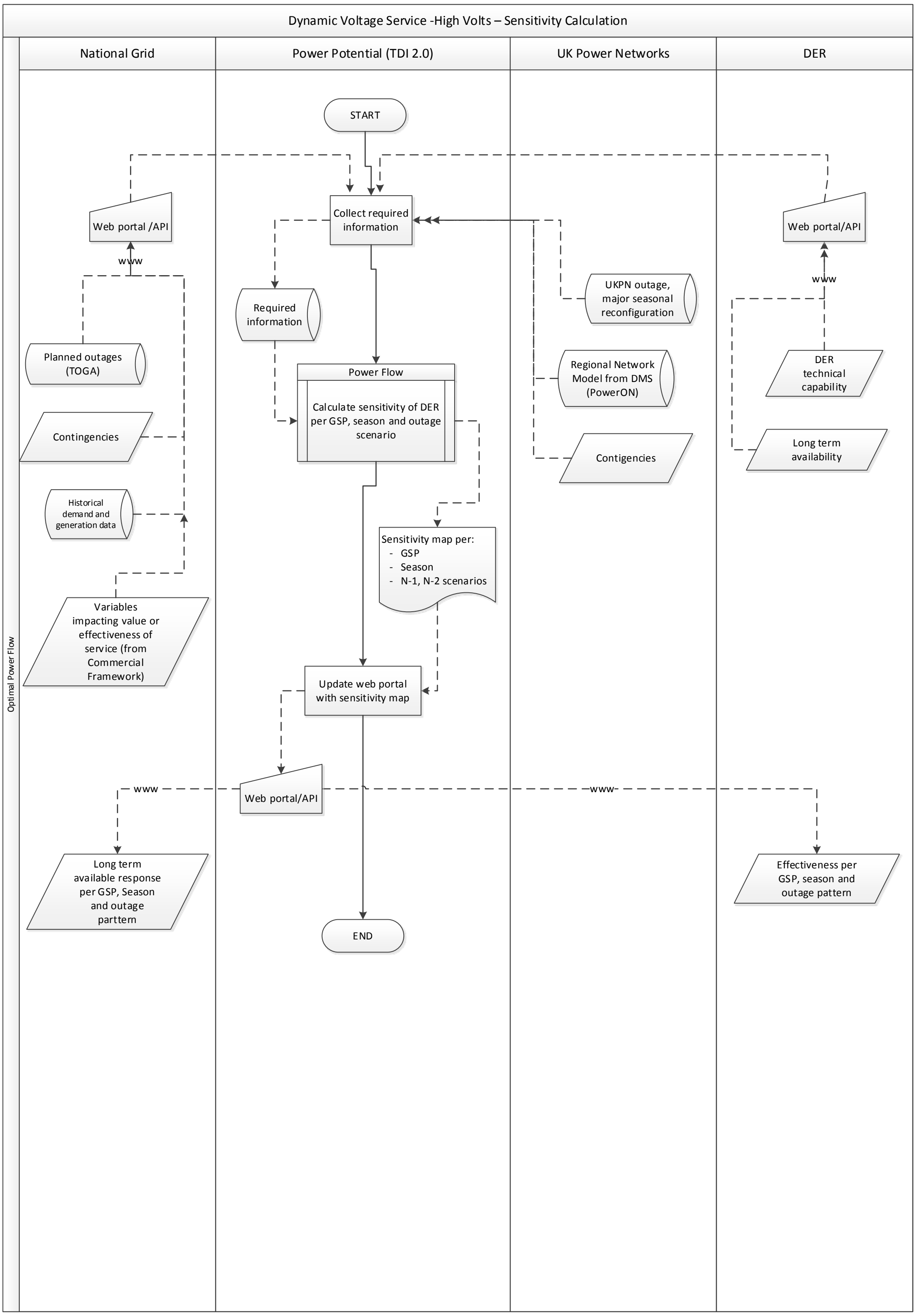
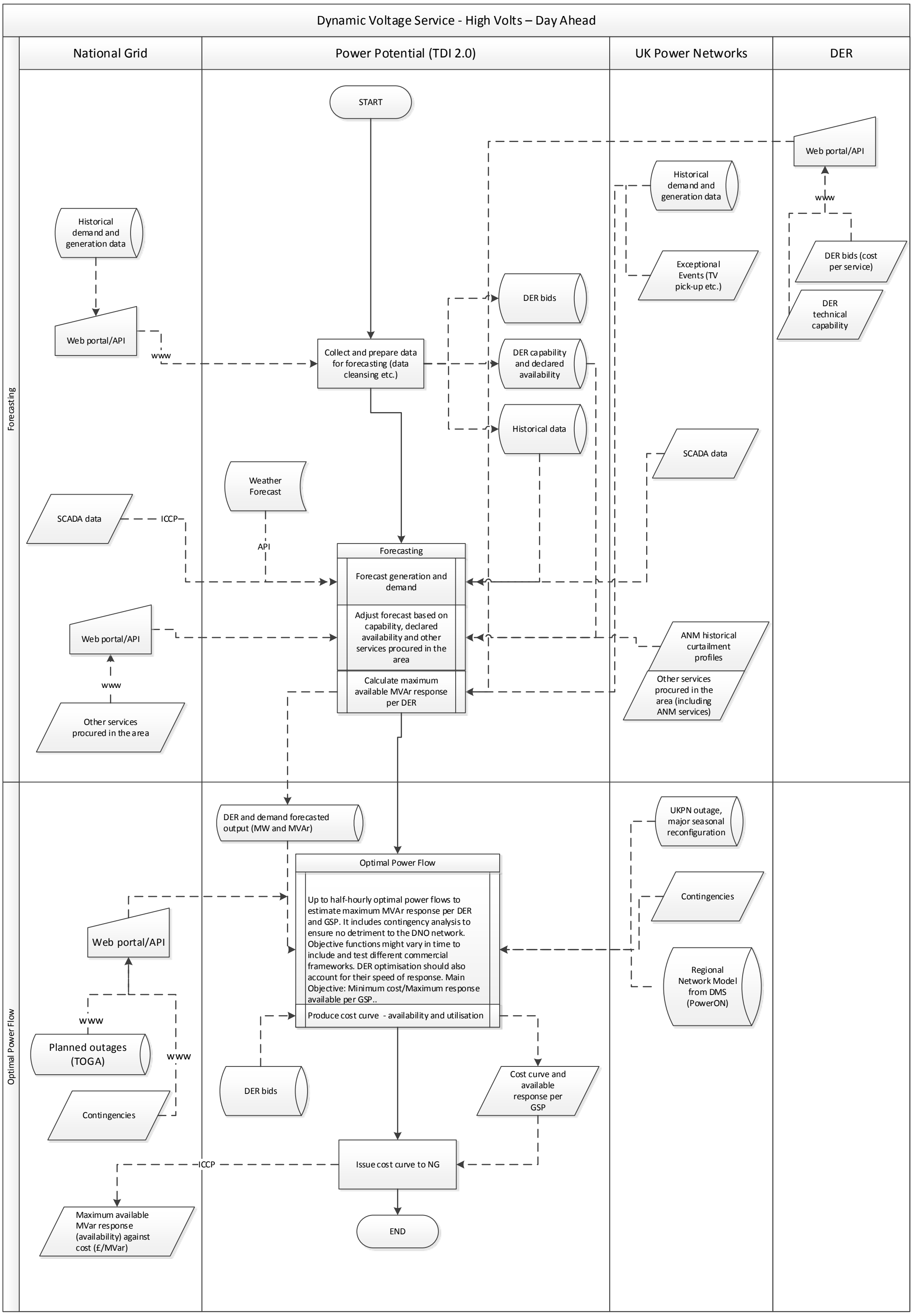


Figure 25 – Sensitivity Calculation – High Voltage Use Case.

Day Ahead

The Day Ahead functionality for High Voltage Use Case is demonstrated in Figure 26:



Up to half-hourly optimal power flows to estimate maximum MVAr response per DER and GSP. It includes contingency analysis to ensure no detriment to the DNO network. Objective functions might vary in time to include and test different commercial frameworks. DER optimisation should also account for their speed of response. Main Objective: Minimum cost/Maximum response available per GSP..

Figure 26 – Day Ahead – High Voltage Use Case.

Service Mode (real–time)

The Service Mode functionality for High Voltage Use Case is demonstrated in Figure 27:

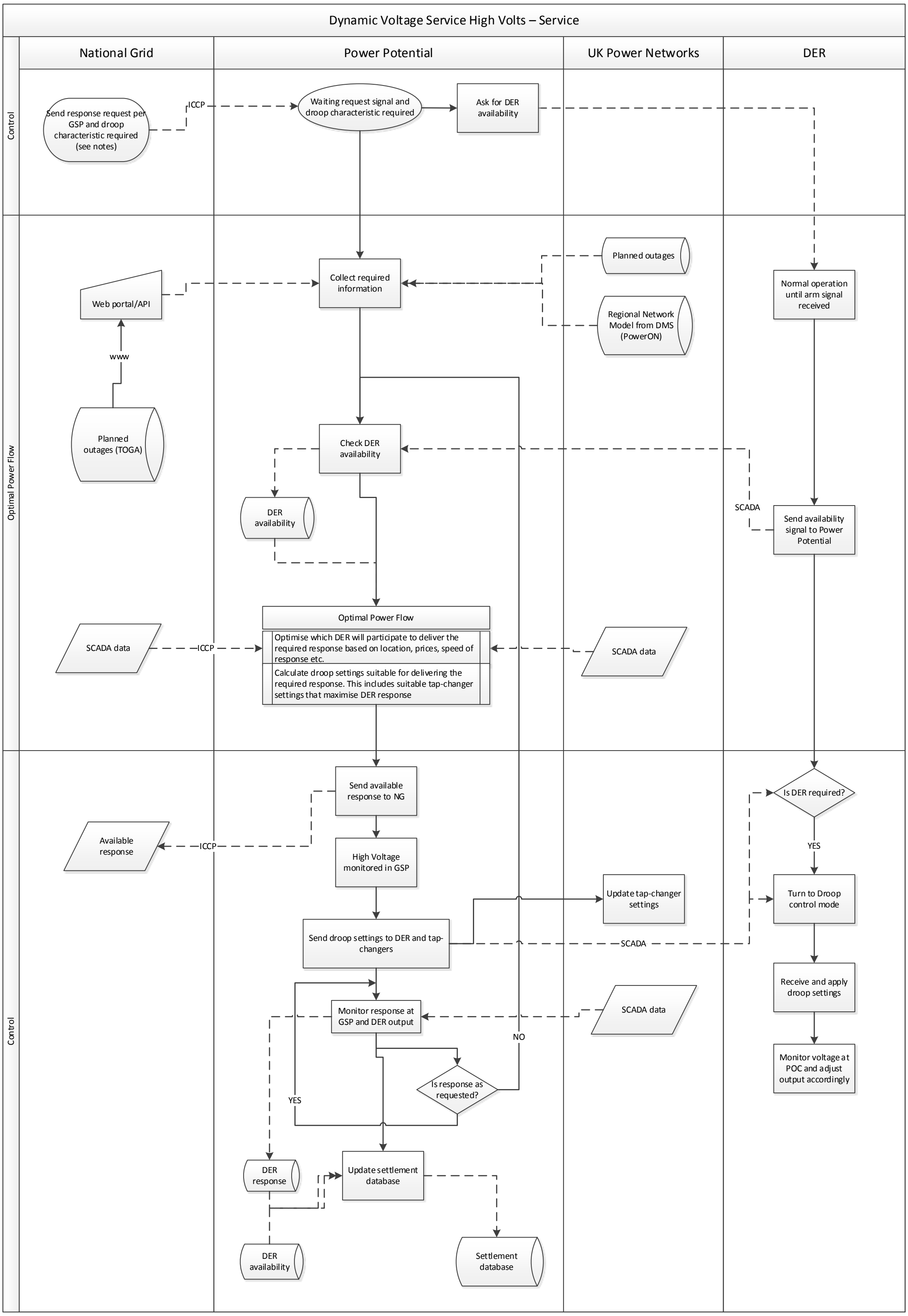


Figure 27 – Service Mode – High Voltage Use Case.

Appendix C – Re–dispatch of Real Power Use Case

Sensitivity Calculation

The Sensitivity Calculation functionality for MW Re–Dispatch Use Case is demonstrated in Figure 28:

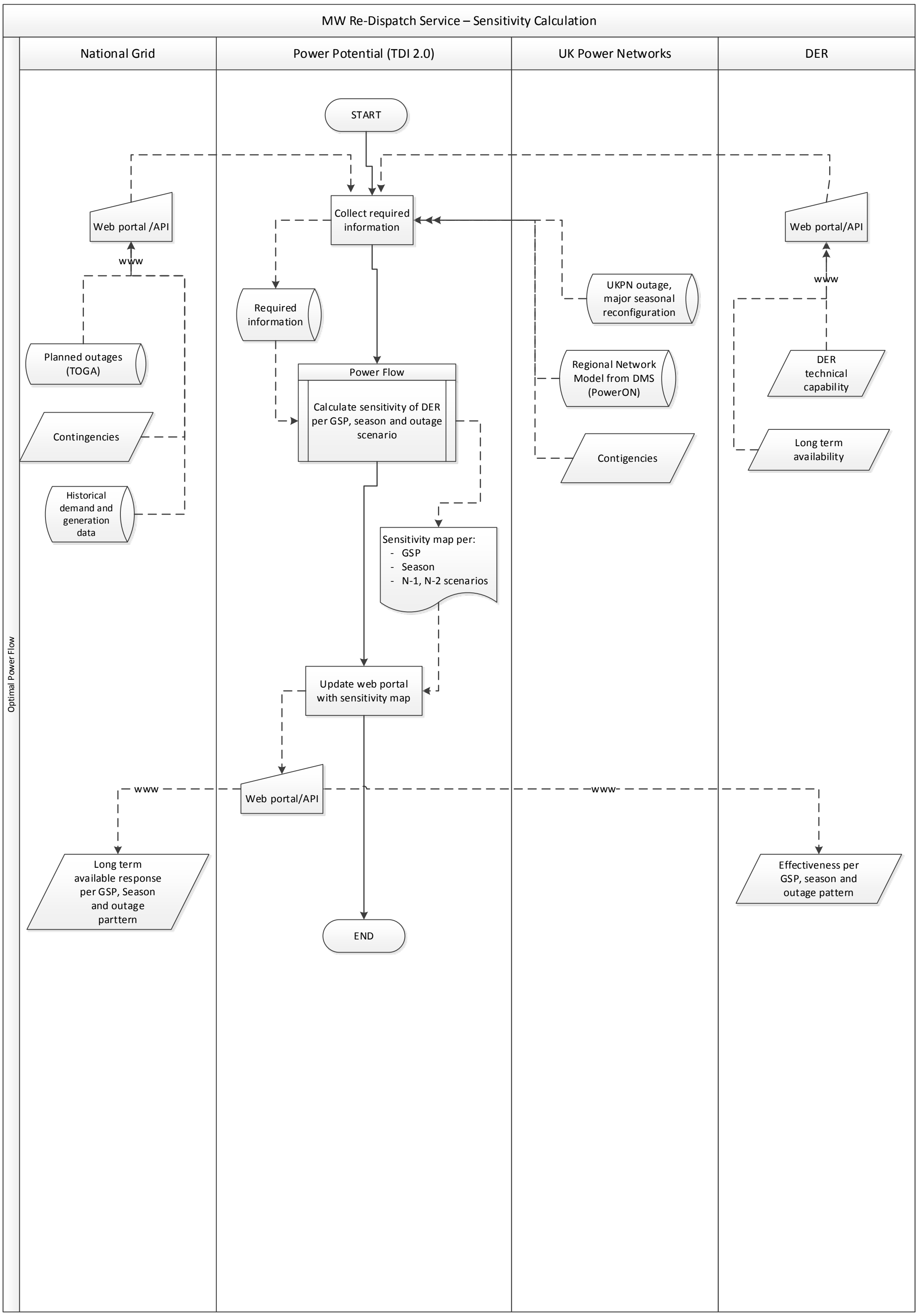


Figure 28 – Sensitivity Calculation – Re–Dispatch of Real Power Use Case.

Day Ahead

The Day Ahead functionality for MW Re–Dispatch Use Case is demonstrated in Figure 29:

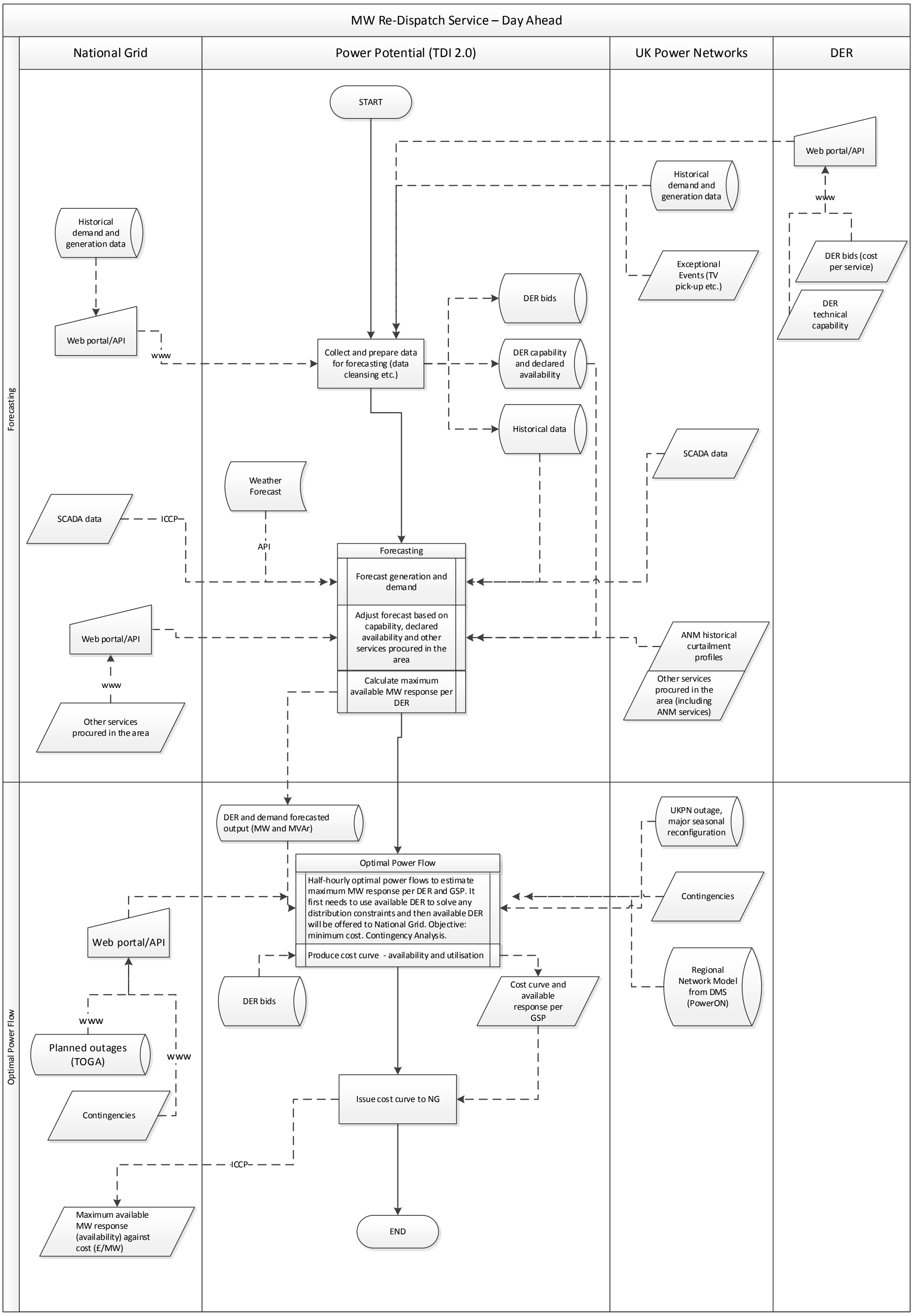


Figure 29 – Day Ahead – Re–Dispatch of Real Power Use Case.

Service Mode (real–time)

The Service Mode functionality for MW Re–Dispatch Use Case is demonstrated in Figure 30:

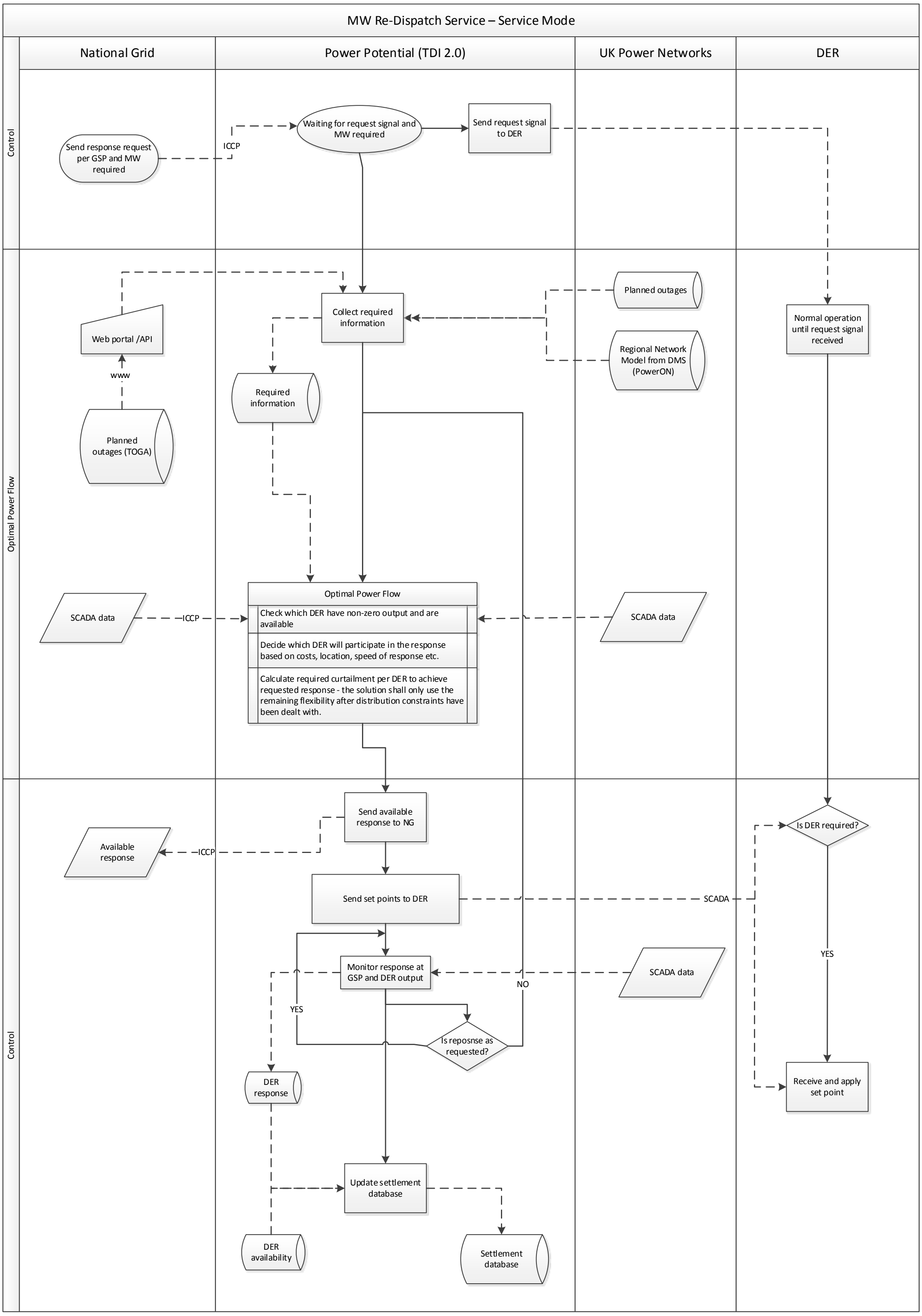


Figure 30 – Service Mode – Re–Dispatch of Real Power Use Case.

Appendix D – Working with academic partners (Confidential)

For confidential reasons the ‘Working with academic partners’ details will not be made available in the public domain and hence redacted.

This appendix is provided in a separate document.

Appendix E – High Level Business Process

APPENDIX E – HIGH LEVEL BUSINESS PROCESS
TDI 2.0

TDI 2.0 Business Process, Level 0

Full Process

Power Potential Service Provision

Service Start

National Grid Instruct Service Requirements per GSP

(Power Potential Request Initiation)

UK Power Networks Receive National Grid Instruction

(Power Potential Request Receipt)

Power Potential System Schedules DER Accordingly

(Scheduling of Distributed Energy Resources)

Power Potential System Monitors DER Output per GSP

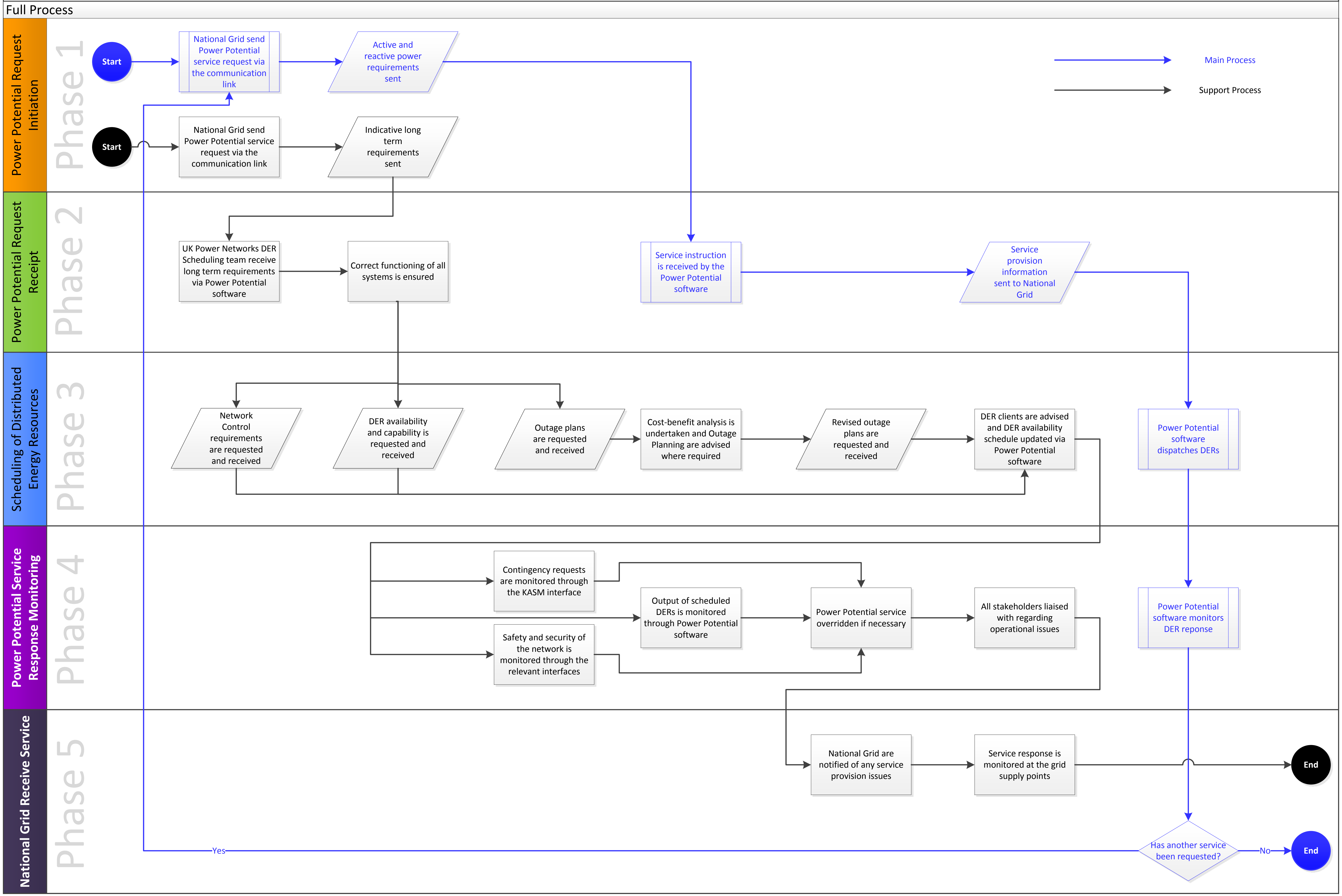
(Power Potential Service Response Monitored)

National Grid Received Service at Grid Supply Point

(National Grid Receive Service)

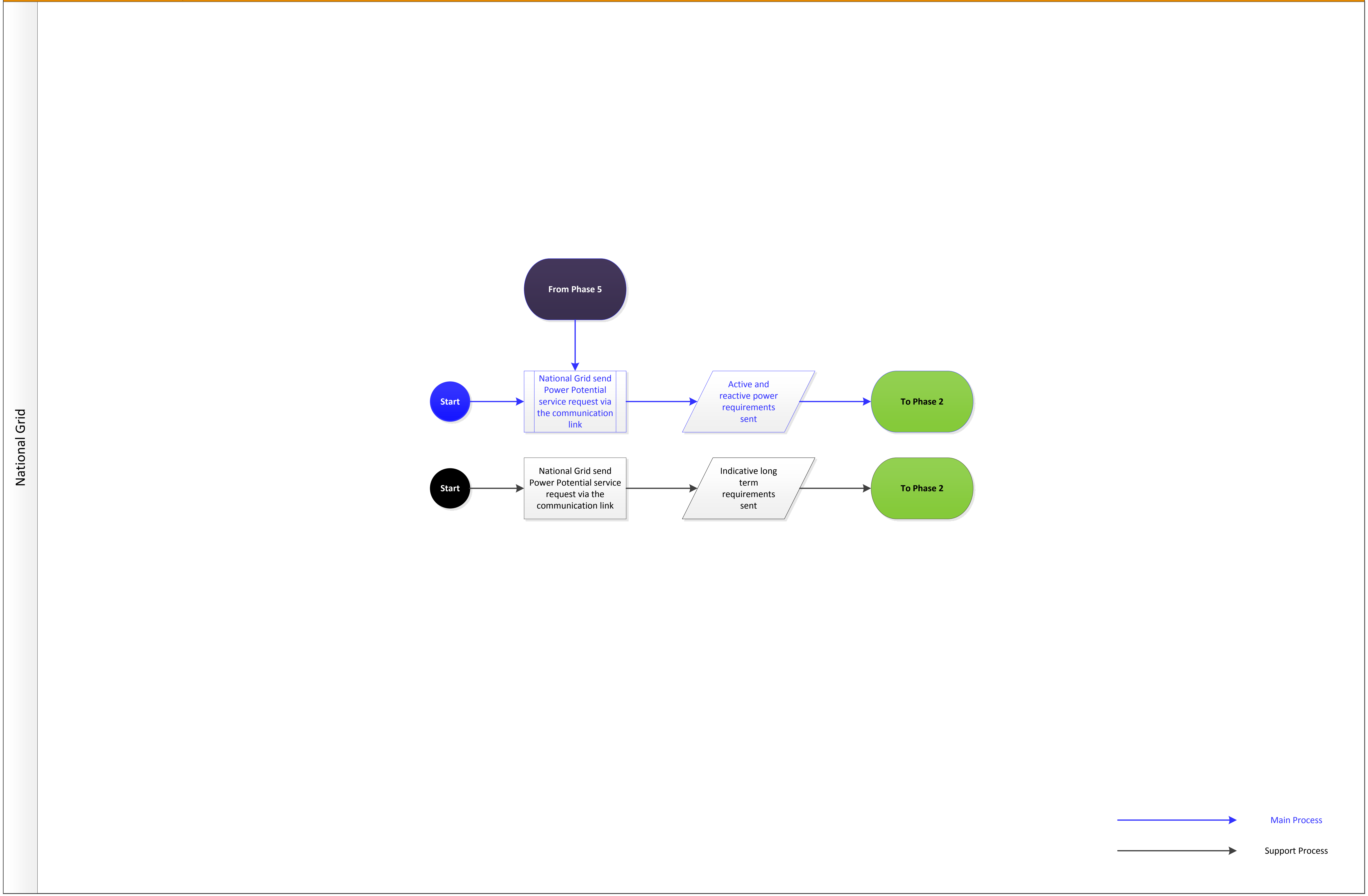
Service End

TDI 2.0 Business Process, Level 1



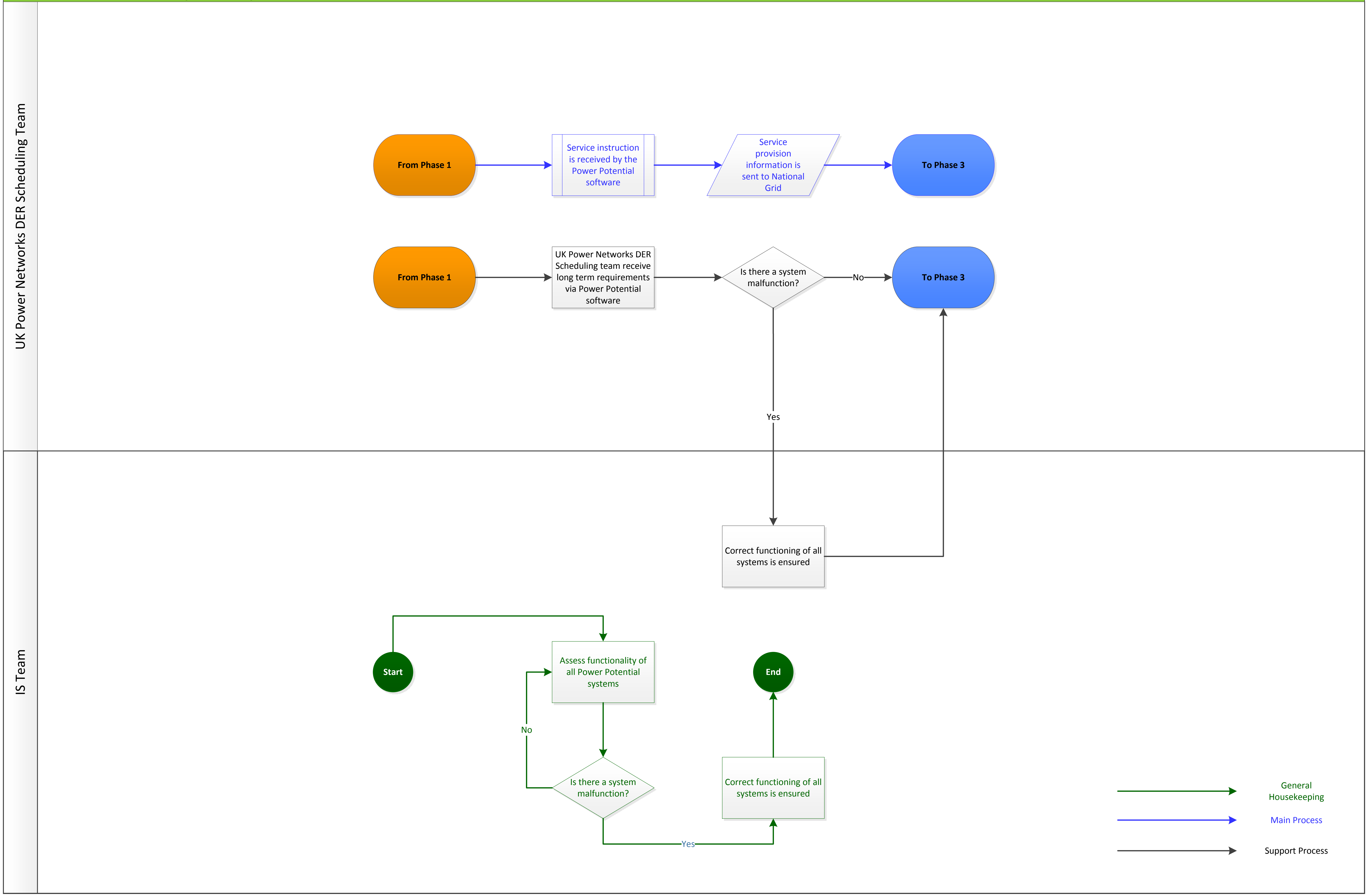
TDI 2.0 Business Process, Level 2

Phase 1 – Power Potential Request Initiation



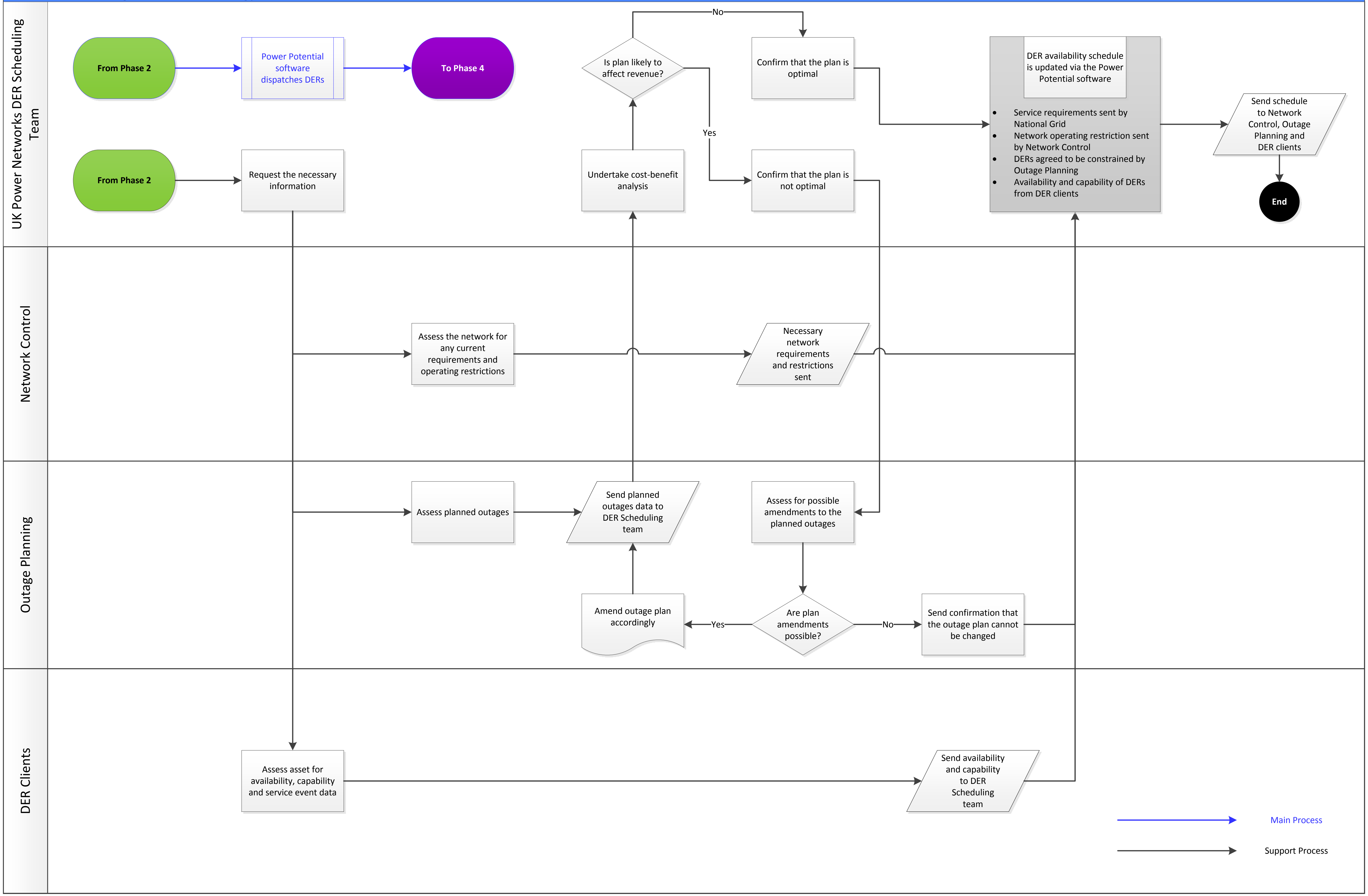
TDI 2.0 Business Process, Level 2

Phase 2 – Power Potential Request Receipt



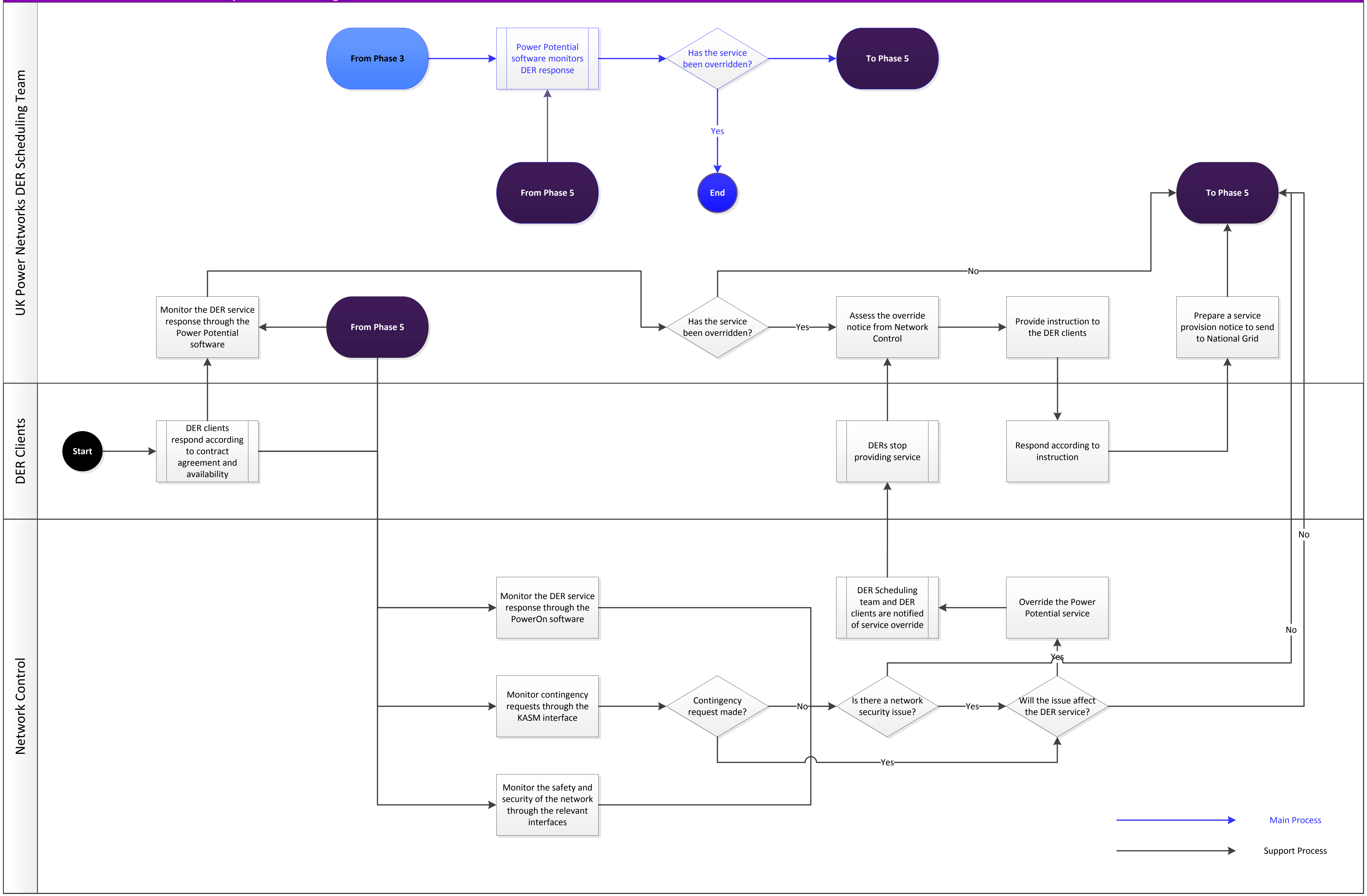
TDI 2.0 Business Process, Level 2

Phase 3 – Scheduling of Distributed Energy Resources



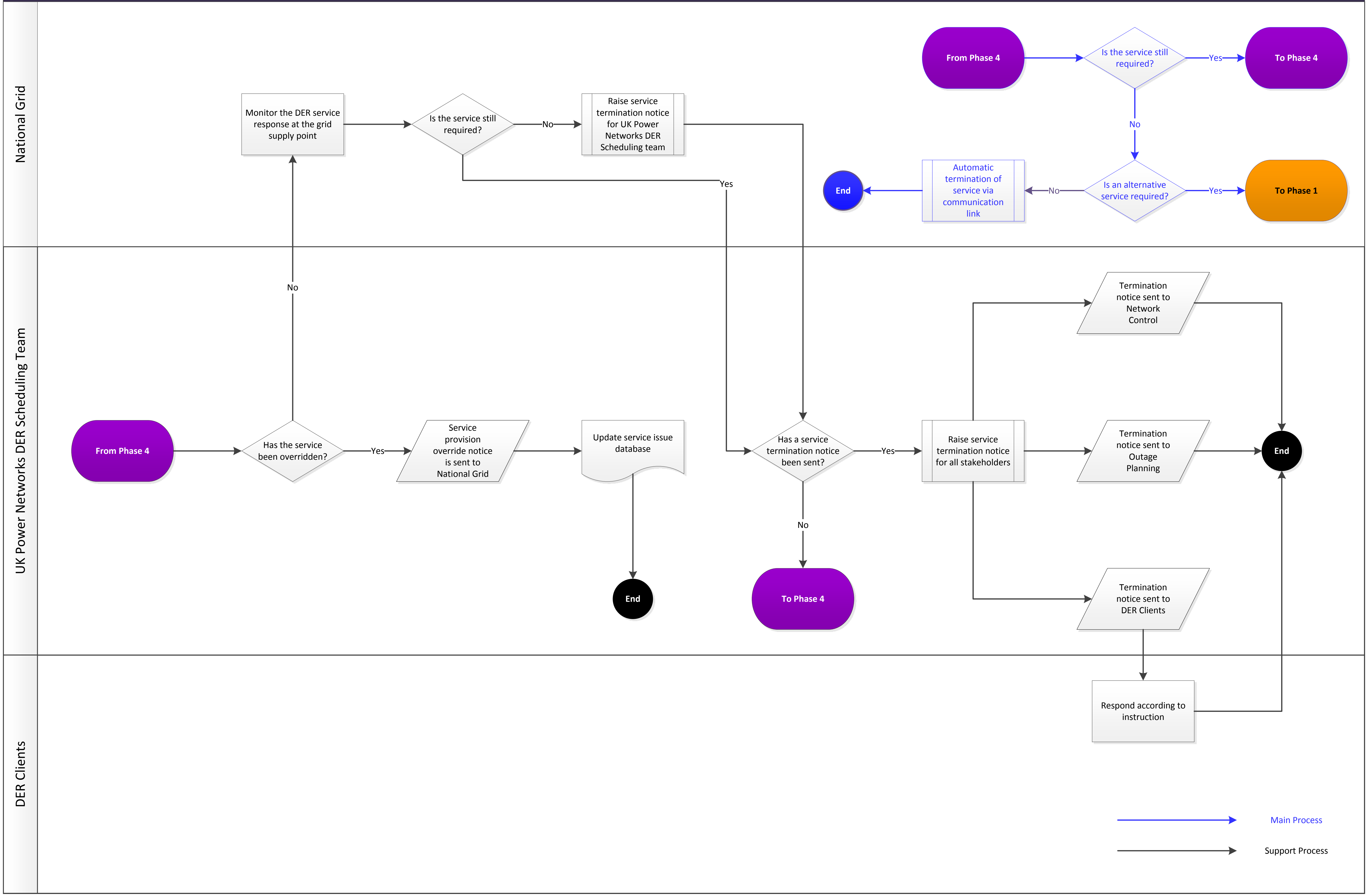
TDI 2.0 Business Process, Level 2

Phase 4 – Power Potential Service Response Monitoring



TDI 2.0 Business Process, Level 2

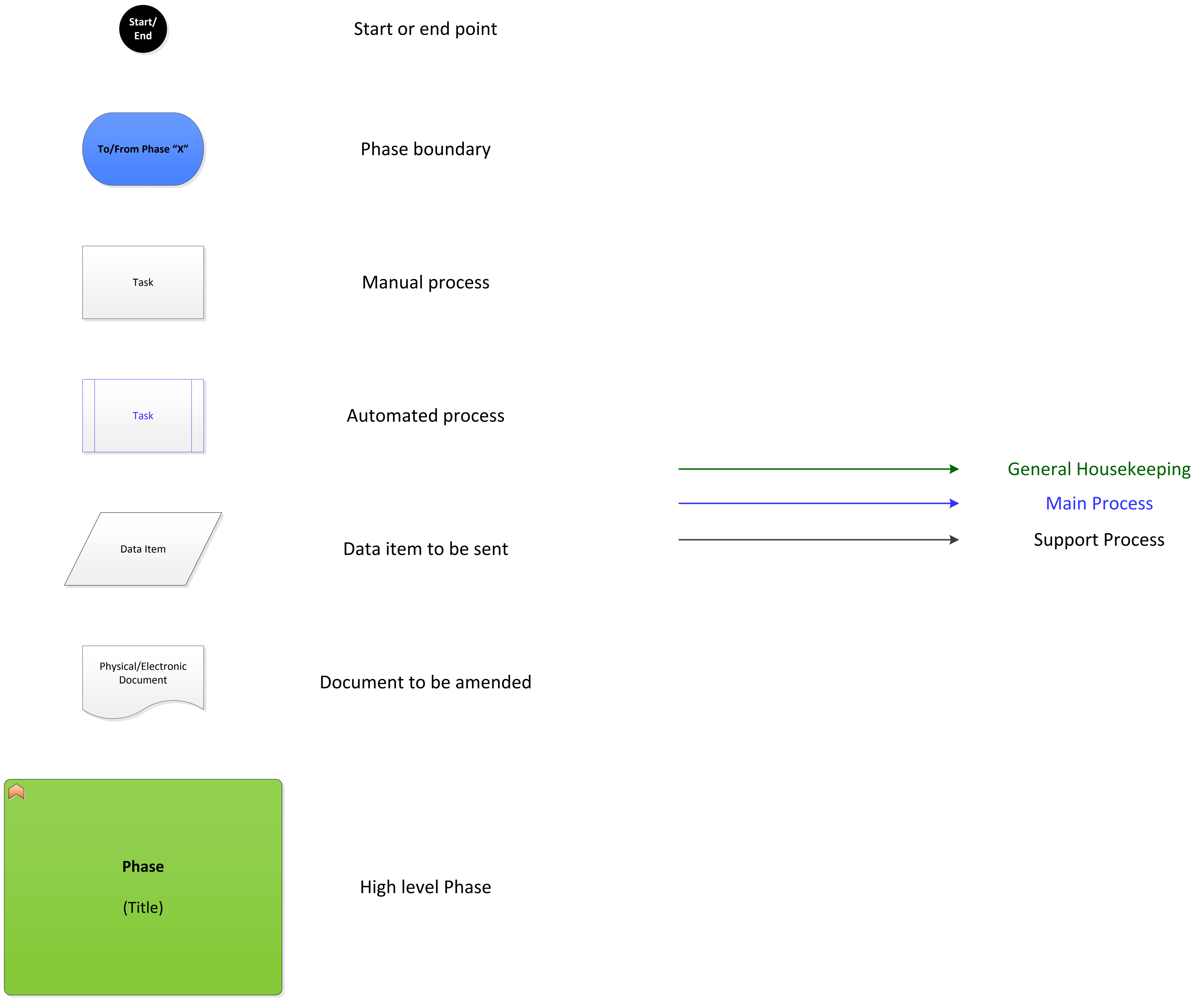
Phase 5 – National Grid Receive Service



TDI 2.0 Business Process, Symbol Key

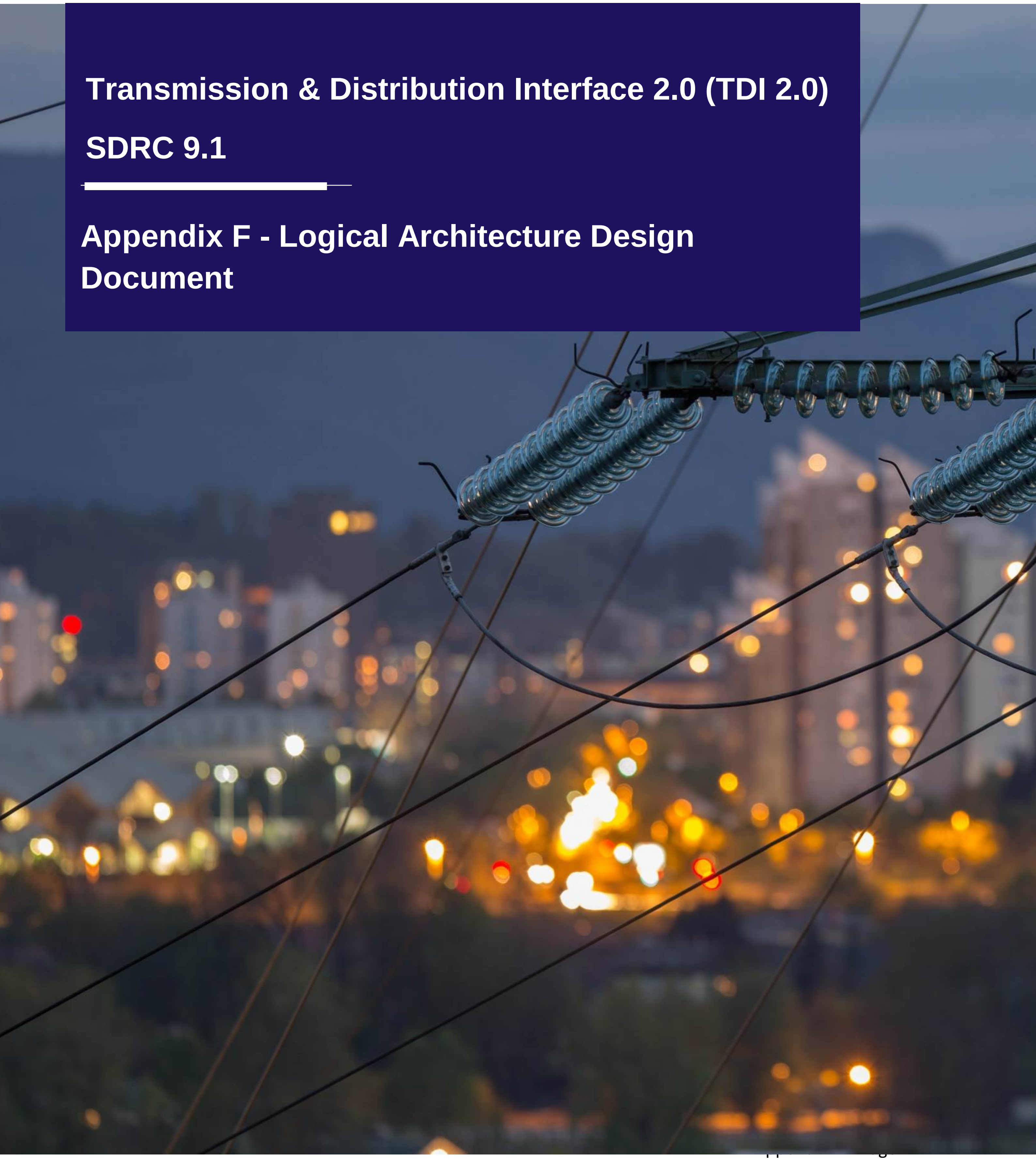
All Phases and Levels

Key to Symbols



Symbol	Meaning
Start/ End	Start or end point
To/From Phase "X"	Phase boundary
Task	Manual process
Task	Automated process
Data Item	Data item to be sent
Physical/Electronic Document	Document to be amended
Phase (Title)	High level Phase

Arrow	Meaning
→	General Housekeeping
→	Main Process
→	Support Process



Transmission & Distribution Interface 2.0 (TDI 2.0)

SDRC 9.1

Appendix F - Logical Architecture Design Document

Working together for a sustainable energy future

Table of Contents

References

Number	Document Name	Author
[1]	TDI 2.0 High Level Design Options v1.1	Tim Manandhar, Ewan Paton, Carolina Escudero and Chris Potter
[2]	Transmission and Distribution Interface 2.0 requirements specification Confidential	Tim Manandhar, Carolina Escudero

Definition of Terms

Term	Definition
ARB	Architecture Review Board
ANM	Active Network Management
BCV	Business Continuance Volume
CIM	Common Information Model
CPU	Central Processing Unit
DC	Direct Current
DER	Distributed Energy Resources
DERM	Distributed Energy Resources Management
DERMS	Distributed Energy Resources Management System
DMS	Distribution Management System
DMZ	De-militarized Zone
DNO	Distribution Network Operator
DR	Disaster Recovery
DSO	Distribution System Operator
EMS	Energy Management System
FC	Fibre Cards
FEP	Front End Processors
FTP	File Transfer Protocol
GDPR	General Data Protection Regulation
GE	General Electric
GIS	Geographic Information System
GSP	Grid Supply Point
HTTP	Hypertext Transfer Protocol
HTTPS	Secured Hypertext Transfer Protocol
ICT	Information Communication Technology
ICCP	Inter-Control Center Communications Protocol
IEC	International Electrotechnical Commission
IP	Internet Protocol
IPS	Secure Internet Protocol
ISO	International Standard Organisation

IT	Information Technology
KASM	Kent Active System Management
MVAr	Mega Volt Ampere Reactive
MW	Mega Watt
NG	National Grid
OPF	Optimal Power Flow
OS	Operating System
P	Active Power in MegaWatts
PACE	Police and Criminal Evidence Act
PC	Personal Computer
PDU	Power Distribution Unit
PED	Personal Electronic Devices
PKI	Public Key Infrastructure
RAID	Redundant Array of Independent Disks
RPO	Recovery Point Objectives
RTO	Recovery Time Objectives
RTU	Remote Terminal Unit
SAN	Storage Area Network
SAP	An Enterprise Resource Planning Application
SCADA	Supervisory Control and Data Acquisition
SCP	Secure Copy Protocol
SDRC	Successful Delivery Reward Criterion
SFTP	Secure File Transfer Protocol
SGAM	Smart Grid Architecture Model
SO	System Operator
SOC	Security Operations Centre
SSH	Secure Shell
TOGAF	The Open Group Architecture Framework
TDI	Transmission and Distribution Interface
UKPN	UK Power Networks
VARs	Volt Ampere Reactive
VLAN	Virtual LAN
VM	Virtual Machine
WAN	Wide Area Network

1. Introduction

1.1 Purpose of Document

The purpose of the Logical Architecture Design Document (LADD) is to document the high level solution that will be developed and delivered.

The LADD is used by the project team during the design phases (Gates B and C) as an output for developing the functional and technical requirements needed for developing the solution documentation (Physical Architecture Design Document) during the System Development Life Cycle (SDLC) to support analysis and design activities. This information can also be used to analyse risks, discuss issues and identify opportunities for shared resources and services at the Enterprise level.

1.2 Document Standards

Specific design decisions will be highlighted as per the following.

Design Decision: - xxxxxxxxxxxxxxxx

Justification: - xxxxxxxxxxxxxxxxx

This allows the most pertinent points of the design to be easily traceable throughout the document and where appropriate to map back specifically to a Functional or Non-Functional Requirement. References to these will requirements will appear either as **FR00X** or **NFR00X**

References to appendices appear as **Appendix X.X**

1.3 Scope

The scope of this paper is the documentation of the high level functional and non-functional requirements for the solution proposed for TDI 2.0. A logical architecture design of the solution will be documented including but not limited to Application, Technology and Security architecture. A brief discussion of options considered and the decisions made is documented in 'TDI 2.0 High Level Design Options v1.1' document and summarised in SDRC 9.1 Section 5.

This document will continued to be updated until the LADD is finalised with the solution vendor. Therefore, these statements are valid until the issuing of this document on 3rd July 2017.

2. Project Background

2.1 Introduction

The Transmission and Distribution Interface 2.0 (TDI 2.0) project aims to create market access for Distributed Energy Resources (DER) to participate in ancillary service provision to National Grid via UK Power Networks' technical coordination. It is envisaged that via the services provided by DER, both transmission and distribution constraints can be managed unlocking whole systems benefits such as additional generation capacity and operational cost savings to customers. The project's approach will be trialled in the South East coast network where a significant uptake of low carbon energy resources have exacerbated technical constraints in the area.

Capacity to connect more generation on the South East of England, namely Grid Supply Points (GSPs) in Canterbury, Sellindge, Ninfield and Bolney, is being restricted due to upstream constraints on National Grid's transmission network. The constraints National Grid face in this area have been driven by the previous growth in low carbon technologies connecting to the distribution network and can be summarised as:

- High voltage in periods of low demand;
- Low voltage under certain fault conditions;
- Thermal constraints during the outage season.

These constraints have led to the following challenges in the area:

- Fewer low carbon technologies can connect;
- High risk of operational issues in the network which could affect customers;
- High costs of managing transmission constraints.

In order to provide voltage support in the area, increasing reactive compensation is needed. DER connected in the distribution network have the potential to provide reactive and active power services to the system. TDI 2.0 seeks to give National Grid access to resources connected to UK Power Network's South Eastern network to provide it with additional tools for managing voltage transmission constraints.

The TDI 2.0 project will include the creation of a regional reactive power market which will be the first of its kind in the Great Britain and help defer network reinforcement needs in the transmission system.

The project will help enable more low carbon resources to connect in the South East and for new and existing DER with the possibility of providing services to National Grid and accessing additional revenue streams. Services procured from DER will be coordinated such that operation of the distribution and transmission networks are kept within operational limits and constraints are not breached. When deployed, TDI 2.0 can deliver:

- 3,720 MW of additional generation in the area by 2050
- Savings of £412m for UK consumers by 2050

2.2 Solution Overview

The problem to be solved is how UK Power Networks can facilitate a new market place allowing DER connected to the distribution network to bid to provide services requested by National Grid as System Operator of the transmission network. In order to do so, the project will have to host a service which allows DERs to:

- Post look ahead bids to UK Power Networks;
- UK Power Networks to determine what effect each DER will have at the National Grid GSPs (sensitivity calculation);
- National Grid to be able to send requests for service to UK Power Networks; and
- UK Power Networks to determine the best technical and lowest service cost solution and present this offer to National Grid and if accepted by National Grid to instruct the DER to action their offer. Finally, the solution will need to support the financial transaction between National Grid, UK Power Networks and the DER customers or aggregators. The solution will not be needed to handle the financial transactions, but will need to provide data which allows this to be handled by an external system.

The solution consists of adding several new capabilities and integrating these some existing services/applications to enable UK Power Networks to coordinate the new marketplace which enables DERs connected to the distribution network to offer services back to the transmission network. The proposed solution will make use of PowerOn for:

- SCADA communications to DER sites;
- The 'as running' network model for both the distribution network and the transmission network; and
- The near real time switch/Circuit Breaker states and analogue points. The solution will also look at historic telemetry data which resides within the UK Power Networks PI data historian and require weather forecast data from the Met Office data feed.

A conceptual view of the proposed solution is shown below in Figure 1 - Context diagram.

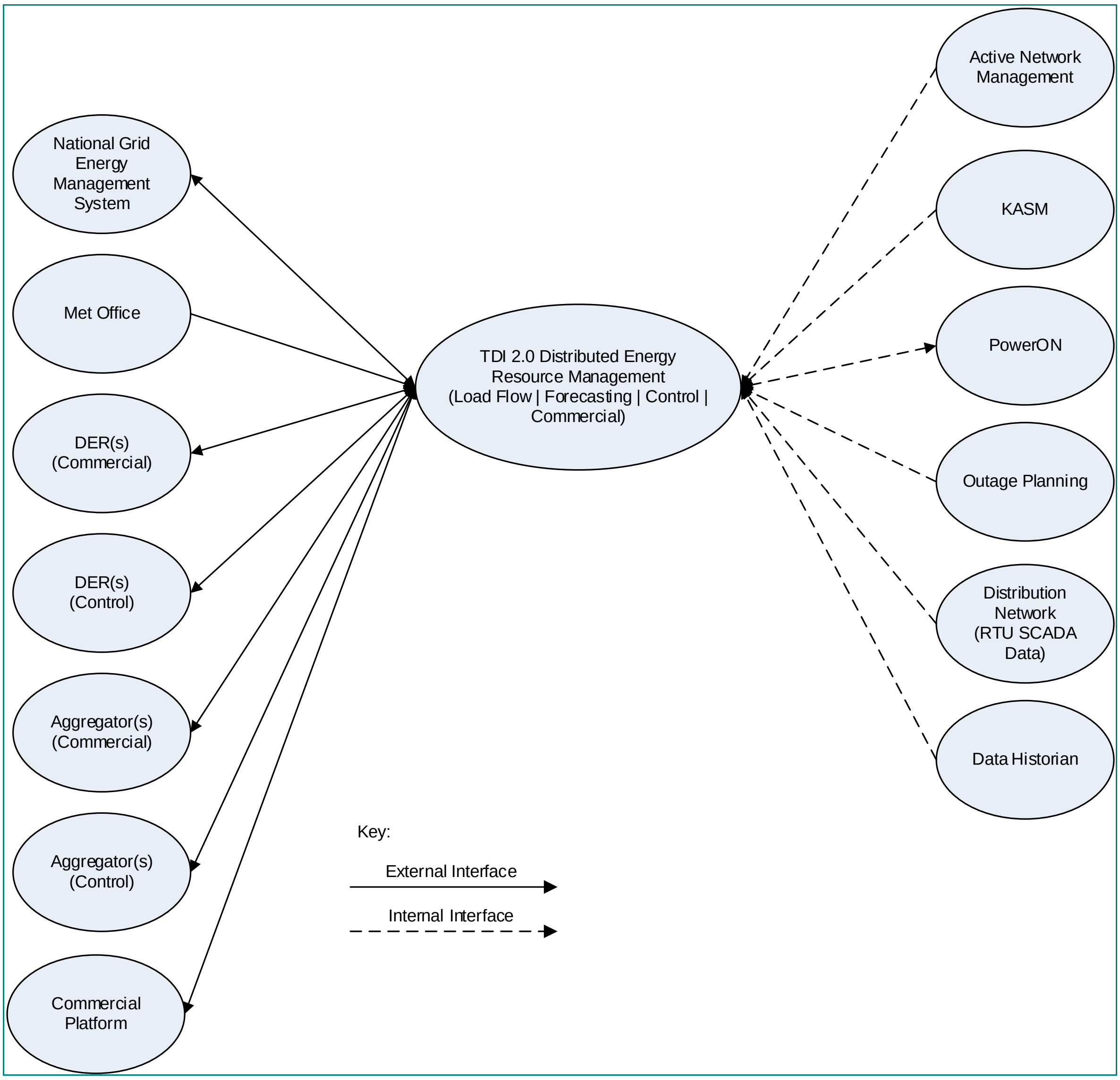


Figure 1 - Context diagram

2.3 Solution Objectives

The solution objectives include:

- Provide a method which allows the DNO (UK Power Networks) and the SO (National Grid) to interact in real time.
- To allow DERs to be able to:
  - View requests for service from the SO or the DNO;
  - Place offers for service provision ahead of time;
  - Receive controls to deliver services; and
  - Provide feedback to show services are being delivered as offered.

2.4 Strategic Alignment

UK Power Networks needs to transition to and support the future energy market where generation will not only be centralised on the transmission network, but will also be widely connected to the distribution network. The project supports the transition to this new model where UK Power Networks will move towards a DSO and acquire several new capabilities to support this additional role. TDI 2.0 also enables the transition for National Grid to the Future Role of the SO. The TDI 2.0 project will develop some of these new capabilities including:

- Optimal Power Flow Calculation;
- Forecasting Engine;
- DER Interfaces;
- SO to DNO interfaces and Connectivity Model Sharing; and
- Commercial Settlement Platform Integration.

With regards to the solution hosting the project is currently considering the possibilities of cloud hosting and virtualisation to obtain cost and scalability benefits. These options will be determined with the solution vendor.

Where appropriate the concept of loosely coupled interfaces will be adhered to by using the enterprise service bus, which aligns with UK Power Network's IS strategy.

2.5 Critical Success Factors

The project goals are as follows.

- To use embedded generation in the distribution network for reactive power;
- To deliver a holistic transmission and distribution system integration using new technologies;
- To put in place a commercial framework that ensures collaborations and effective working with Distributed Energy Resources;
- The project will provide a flexible and sustainable solution to the future needs of the system

Therefore, in order to achieve these goals, key success factors include:

- Obtain DER customers who are willing to participate in the trial;
- Demonstrate that services can be procured by the SO to the DER via the DNO in accordance to the time service constraints;
- Developing a robust method of exchanging and making available the 'as running' network model from the DMS (PowerOn); and
- Solution integration – There are a number of key systems which will need to be able to communicate with each other. These interfaces should be reliable and their performance will be key to meet the service time constraints.

2.6 Benefits

The benefits of the project are:

- To enable DER customer connections in the area up to 3,720 MW by 2050; and
- Savings of £412m for GB consumers by 2050

2.7 User Requirements

The functional and non-functional requirements have been collated in the 'TDI Solution Requirement Specification document v1.1' document referenced. A subset of these are:

2.7.1 Functional Requirements

Requirement ID	Description
FR001	Solution must be able to gather capability information from DER participants
FR002	Solution must be able to collect availability data from DER participants
FR003	Solution must be able to receive cost information from DER participants
FR004	Solution must be able to calculate generator sensitivity factors for each DER
FR005	Solution must be able to monitor the DER’s output to ensure it meets the service offered
FR006	Solution must be able to use the ‘as running’ network model
FR007	Solution must be able to calculate the best technical, lowest cost solution
FR008	Solution must be able to provide settlement data to the commercial platform
FR009	Solution must be able to share SCADA data with the TSO systems

2.7.1 Non-Functional Requirements

Requirement ID	Description	Category
NFR001	Solution must respond to requests in 10 seconds in accordance to each service requirement detailed in SDRC 9.1 Section 3.	Performance
NFR002	Solution must be able to support heterogenous DER partcipants without scalability limits	Scalability
NFR003	Solution must have the same support level as the DMS	Availability
NFR004	All commercial data should be encrypted at rest and in motion	Data Protection

3. Business Architecture

3.1 Introduction

3.1.1 As-Is Business Architecture

The DERMS solution will be installed in UK Power Network’s control room as currently UK Power Networks do not provide this type of technical coordination to offer services to National Grid from DER connected in their network.

3.1.2 To-Be Business Architecture

As the project developed and high level impacted business processes where analysed, it was promptly identified that existing processes within UK Power Networks would require changes and business teams to accommodate the new service provision. Therefore, it was necessary to develop an entirely new business process and scheduling team for delivering the TDI 2.0 services.

In order to operate the solution, the processes will be largely be automated with manual intervention for support and general housekeeping requirements. The identified high-level process will be amended and augmented as the TDI 2.0 project progresses.

At this stage, the main affected teams or actors within UK Power Networks are Network Control, Outage Planning, and Information Services. Of these, Network Control and Outage Planning will have significant active roles within the overall support process for TDI 2.0, and Information Services will have the responsibility of maintaining the operational status of the software developed for the TDI 2.0 service.

The new team, the DER Scheduling team, will be responsible for the operation of the TDI 2.0 service within UK Power Networks. They will have operational ownership of the DERMS platform, undertake all engagement with external stakeholders, particularly National Grid and the DER clients, undertake all advance scheduling of DERs for the service, liaise with internal stakeholders regarding security issues and monitor the service response. As the scheduling DERs for the service will require commercial knowledge, it is anticipated that the typical member of this team will have commercial analysis skills as well as control room network management expertise.

More information on the to-be business process is provided in SDCR 9.1 Section 8.

4. Data Architecture

4.1 Introduction

The DERMS solution will bring new data items into the enterprise data model. It will also need to utilise data from existing sources. The solution works on the principle of mastering data in a single system and then using interfaces to populate this into subscriber systems, utilising loosely coupled integration via the enterprise service bus where possible. Any SCADA based communications will use the same data objects which are in use with PowerOn in the as-is model.

4.2 Data Dictionary

The Detailed design phase will take place after SDRC 9.1 and the data dictionary will be defined at this stage.

4.3 Logical Data Model

4.3.1 As-Is Data Model

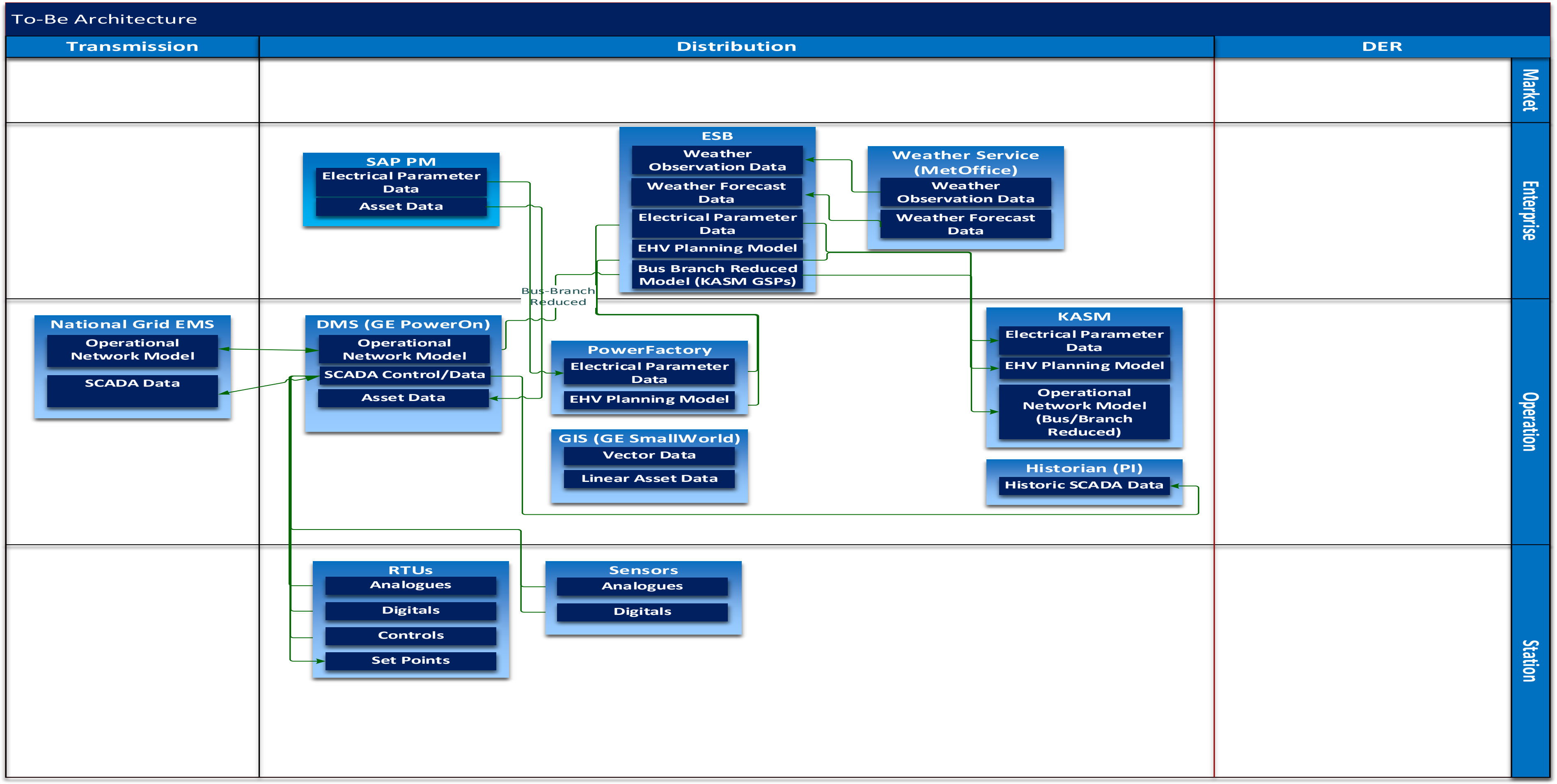


Figure 2 – As is Model

4.3.2 To Be Data Model

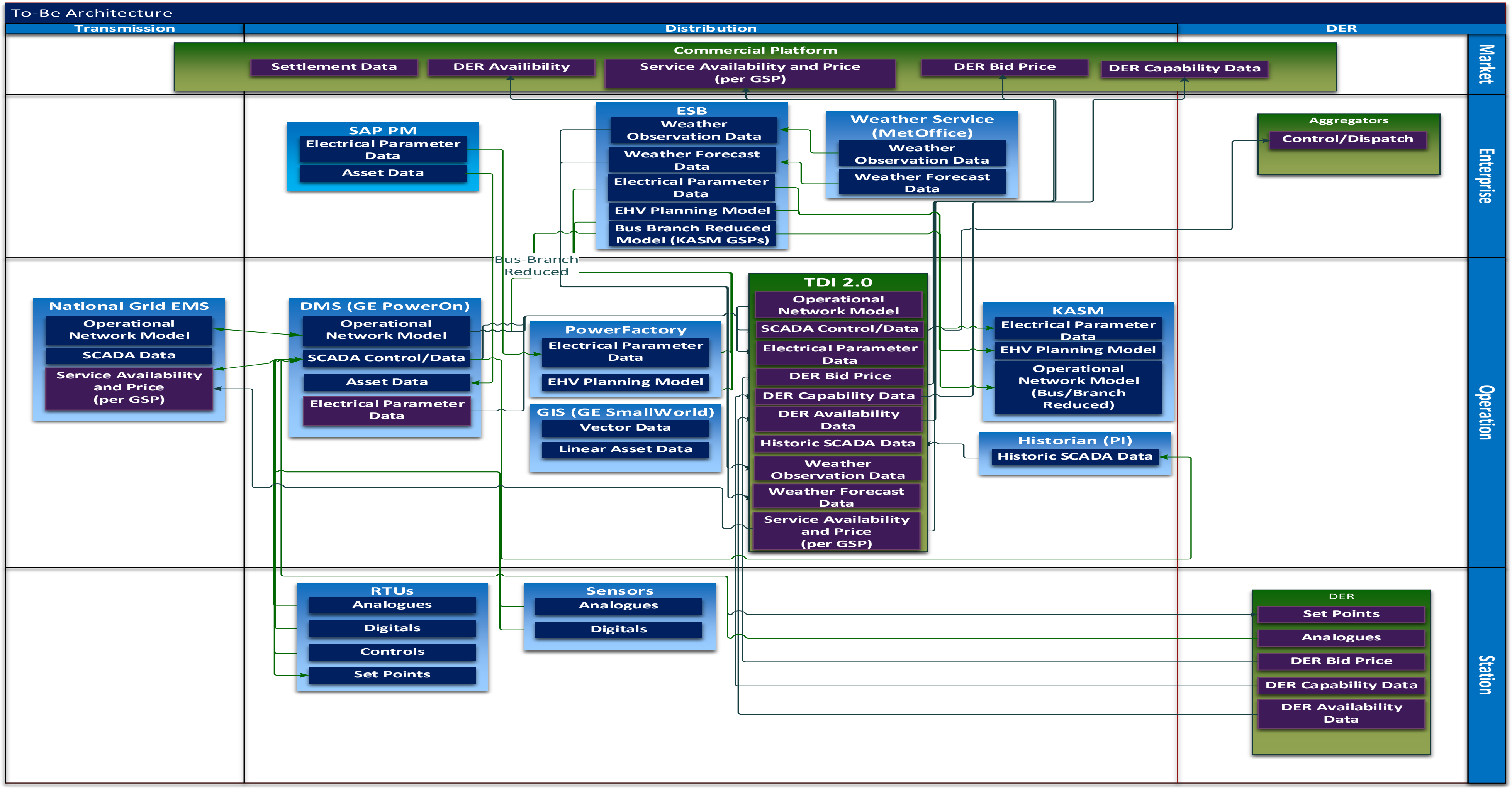


Figure 3 – To be data mode

5. Application Architecture

5.1 Application Components

The key application components are listed in Table 1 and provides an overview of the existing and new components that will interact with the solution.

ID Number	Software Component	Explanatory Notes	System
1	ICCP	Inter Control Centre Protocol	PowerOn(Existing)
2	CIM	Common Information Model (if feasible within project timelines/budget)	PowerOn(New)
3	EMS	National Grid's control system	(Existing)
4	PowerOn	UK Power Networks' distribution management system. Supports all SCADA, operations, outage, network model data	PowerOn(Existing)
5	Enterprise Service Bus(ESB)	The messaging platform which supports the data messaging between applications	IBM Integration Bus(Existing)
6	Front End Processor(FEP)	The component which deals with SCADA communication out to field devices and integrates to the DMS	PowerOn component(Existing)
7	Data Historian	The repository for historic telemetry data	OSISoft PI(Existing)
8	DERMS	Distributed Energy Resource Management System. This is the solution will carry out the three key new functions (Forecasting, Control & Dispatch, Optimal Powerflow)	TBC(New)

Table 1 Application components

5.2 Logical Application Architecture Diagram

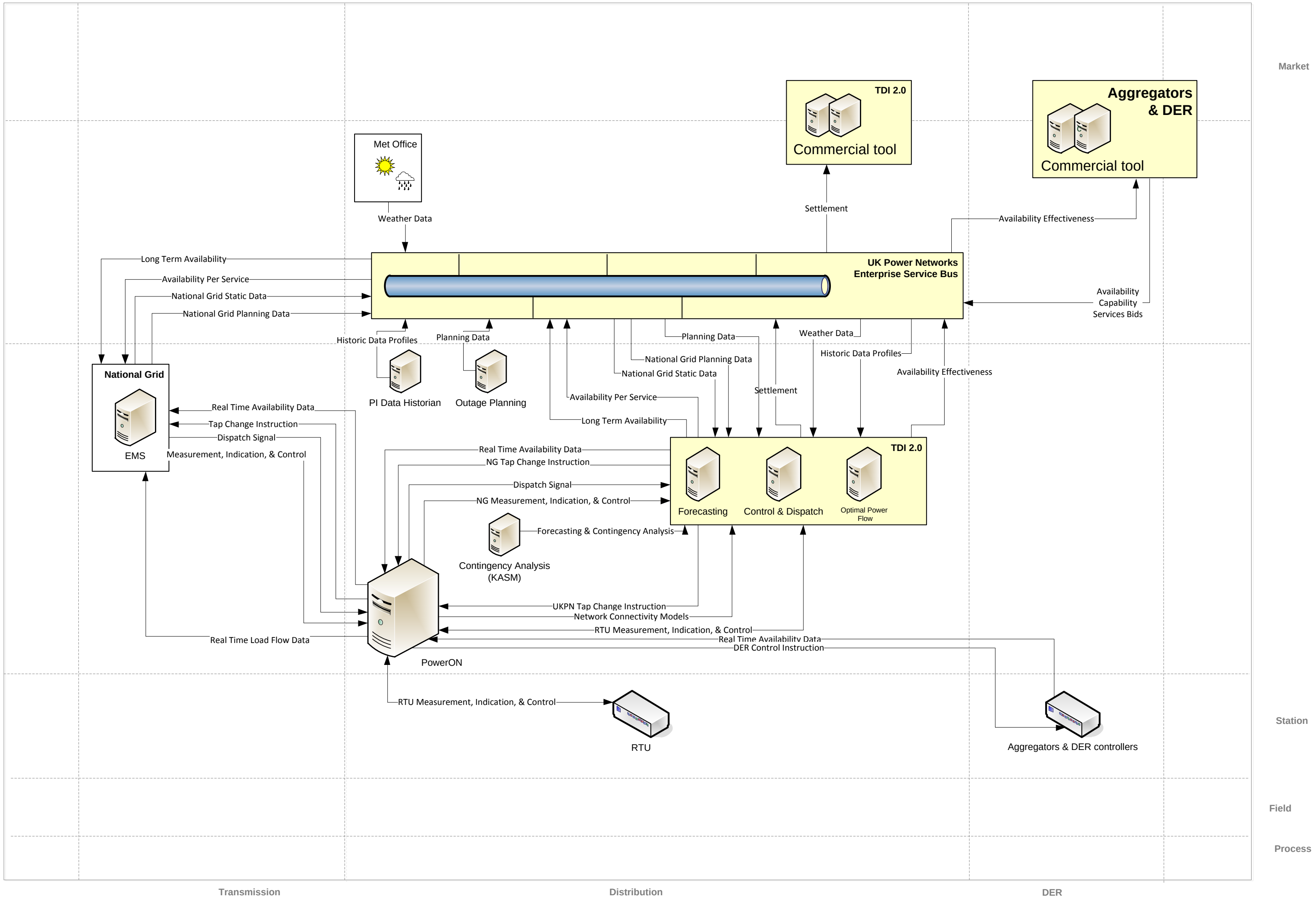


Figure 4 - Logical Interfaces based on communication layer of SGAM

5.3 Existing Application Architecture Impact

The impacted areas of the targeted solution are around the integration of the new TDI 2.0 application into the existing UK Power Networks' IS framework. The TDI 2.0 solution will have independent functionalities will need to be integrated with PowerOn to enable all of the communications between the DERs and National Grid. It will also require certain data feeds in, such as the weather forecast data from the Met Office, historic telemetry data and planning data. These additional data feeds are envisaged to take place via the enterprise service bus in the form of an XML payload.

5.4 Application Integration

The proposed integration is described in Figure 4above in section 5.2. The description of the interfaces required for the solution is below in Table 2 - Interfaces.

Interface Name	Protocol	Source System Component	Target System Component	Data	Interface Purpose
Historic Profiles	To be decided during detailed design	UK Power Networks' Active Network Management (ANM)	Distributed Energy Resource Management (DERM)	Historic curtailment profiles and other services procured	Data will be used by the Distributed Energy Resource Management (DERM) component to calculate dispatch availability.
Historic Data Profile	To be decided during detailed design	Data Historian	DERM	This data will include historic demand and generation	Data will be used by the Distributed Energy Resource Management (DERM) component to perform load flow calculations.
Availability	To be decided during detailed design	Distributed Energy Resource (DER)	DERM (via ESB[1])	Generation availability	Data will be used by the Distributed Energy Resource Management (DERM) component to calculate dispatch availability.
Capability	To be decided during detailed design	DER	DERM (via ESB)	Generation capability	Data will be used by the Distributed Energy Resource Management (DERM) component to calculate dispatch availability.

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[1] UK Power Networks' Enterprise Service Bus

Interface Name	Protocol	Source System Component	Target System Component	Data	Interface Purpose
Services Bids	To be decided during detailed design	DER	DERM (via ESB)	Commercial bid information	Commercial bids for generation capability and available to be used by the DERM for commercial optimisation of services.
Real Time Availability Data	To be decided during detailed design	DER	DERM (via PowerON)	Real time generation availability data	Data will be used by the Distributed Energy Resource Management (DERM) component to calculate dispatch availability.
Long Term Availability	To be decided during detailed design	DERM (via ESB)	National Grid (NG) Energy Management System (EMS)	Geographic network map indicating availability per service and per GSP	Data will be used by National Grid (NG) Energy Management System for selecting the appropriate service required.
Availability Effectiveness	To be decided during detailed design	DERM (via ESB)	DER	Geographic network map indicating availability per services and per GSP	Data will be used by the DER to assess their effectiveness.
Availability Per Service Cost Curve	To be decided during detailed design	DERM (via ESB)	NG EMS	Price and capacity data	Aggregated availability per Grid Supply Point (GSP) per service to enable National Grid to make decisions upon which services are the most cost effective to procure at a given time.
DER Control Instruction	To be decided during detailed design	DERM (via PowerON)	DER	Generation control instructions including voltage droop settings / MW settings, and voltage set points.	Instructions to the DER to provide a certain amount of service response.
Aggregator Control Instruction	To be decided during detailed design	DERM (via PowerON)	Aggregator	Generation control instructions including voltage droop settings / MW settings, and voltage	Instructions to an Aggregator to provide a certain amount of service response.

Interface Name	Protocol	Source System Component	Target System Component	Data	Interface Purpose
				set points.	
Real Time Availability Data	ICCP	DERM (via PowerON)	NG EMS	Real time generation availability data, and acknowledgement of instruction messages.	Data will be used by National Grid Energy Management System to understand UK Power Networks' dispatch availability.
UK Power Networks' Tap Change	ICCP	DERM (via PowerON)	PowerON	Tap change control instruction	Control instructions to maximise the generation response.
National Grid Tap Change	ICCP	DERM (via PowerON)	NG EMS	Tap change control instruction	Control instructions to maximise the generation response.
Settlement	To be decided during detailed design	DERM (via ESB)	Commercial portal	Bid settlement information	To be used by the commercial portal to settle bids with the DERs and/or Aggregators.
Electrical Parameters	To be decided during detailed design	DigSILENT	PowerON	Data include asset parameters such as ratings, impedences, fault level contributions amongst others.	Data will ultimately be used by the Distributed Energy Resource Management (DERM) component to perform load flow calculations.
Forecasting And Contingency Analysis	To be decided during detailed design	KASM	DERM	Forecasted generation and demand in the area and information about key contingencies potential overloads and mitigation recommendations.	Data will ultimately be used by the Distributed Energy Resource Management (DERM) component to perform forecasting and contingency analysis.
Weather service	HTTP-based Web Service	Met Office (via ESB)	DERM	Weather data	The DERM will use the weather data for forecasting generation availability and demand.

Interface Name	Protocol	Source System Component	Target System Component	Data	Interface Purpose
Measurement, Indication and Control	ICCP	NG EMS	DERM (via PowerON)	SCADA data. Real time measurement and indication data.	The DERM will receive control instructions from National Grid, and will also use measurement and indication data for load flow calculations.
Real time data exchange	ICCP	NG EMS	DERM (via PowerON)	Forecasted data	Forecasting
National Grid Static Data	To be decided during detailed design	NG EMS	DERM (via ESB)	Outages, ratings, electrical changes, and other services procured by NG	The DERM will relay this data to PowerON to feed into the Network Model.
National Grid Dispatch Signal	To be decided during detailed design	NG EMS	DERM (via PowerON)	DER arm, and request service control instructions.	The DERM will use these instructions to either ready itself, and the DERs, for dispatch, or to dispatch a requested service it has previously armed for.
National Grid Planning Data	To be decided during detailed design	NG (Exact system to be determined in detailed design)	DERM (via ESB)	This include outages in the area and possible reconfigurations.	The DERM will use this data to calculate long term sensitivity maps of services
UK Power Networks' Planning Data	Manual update of the DERM system via user interface.	Outage Planning	DERM (via ESB)	Outage lists	This data is used by the DERM to calculate long term sensitivity maps of services.
Regional Network Connectivity Model (Base Case)	To be decided during detailed design	PowerON	DERM	This is the network connectivity model from PowerOn	Data will be used by the DERM component to perform load flow calculations.
Regional Network Connectivity Model (Real Time Model)	To be decided during detailed design	PowerON	DERM	This is again the network connectivity model from PowerOn, but will be the changes to the network state as opposed to the	Data will be used by the DERM component to perform load flow calculations.

Interface Name	Protocol	Source System Component	Target System Component	Data	Interface Purpose
				whole model.	
Real Time Load Flow Data	ICCP or HTTP-based Web Services (To be decided during detailed design)	PowerON	NG EMS	SCADA data	PowerON will make available to National Grid (NG) Energy Management System (EMS) SCADA data to enable NG Control Room to make decisions about service provision
RTU Measurement, Indication and Control	ICCP	RTUs	DERM (via PowerON)	SCADA data. Real time measurement and indication data.	The DERM will send/receive control data to the RTUs via PowerON, and will also use measurement and indication data for load flow calculations.
Remote DERM Vendor Management	VPN (To be decided during detailed design)	Vendor systems	DERM	This will allow the vendor to provide support the application/environment	Vendor remote management of the DERM.

Table 2 - Interfaces

5.5 Solution Options

The solution design options document is referenced for information and summarised in SDRC 9.1 Section 4. These design options will be complemented during the detail design phase with the DERMS vendor.

6. Technology Architecture

To be defined, alongside the vendor during detailed design which will come after the SDRC 9.1 phase. However, the current relevant considerations are summarised in this section.

6.1.1 Data Centre Locations

DERMS will be hosted on premises in UK Power Networks data centres, and may optionally place certain components in the Microsoft Azure cloud platform, if appropriate, for components that need to scale quickly for performance.

For high-availability/disaster recovery, two sites will be used to host the DERMS environments; a Primary (Main Site) and a Secondary (Failover Site). Distance is an important factor between sites.

- The primary site provides business-critical data centre services.
- The secondary site is an alternative facility to which services can be migrated in the event of a failure at the primary site. This is a replication of the production platform which will be used for business continuity during disaster scenarios and planned maintenance.

Each site must have at least one data centre, and the secondary site must have hardware, network, and storage resources that can support the same virtual/physical machines and workloads as the primary site. The sites must be connected by a resilient, secure and high availability IP network.

For components placed in cloud hosting, Microsoft has Azure data centres located around the world. Microsoft Azure services are available in 22 regions across the globe, including in the United States, Europe, Asia, Australia and Brazil and can also provide separated hosting analogous to separate physical data centres in a single region.

6.1.2 Component/Environment Mapping

All environments will host instances of all components in the architecture.

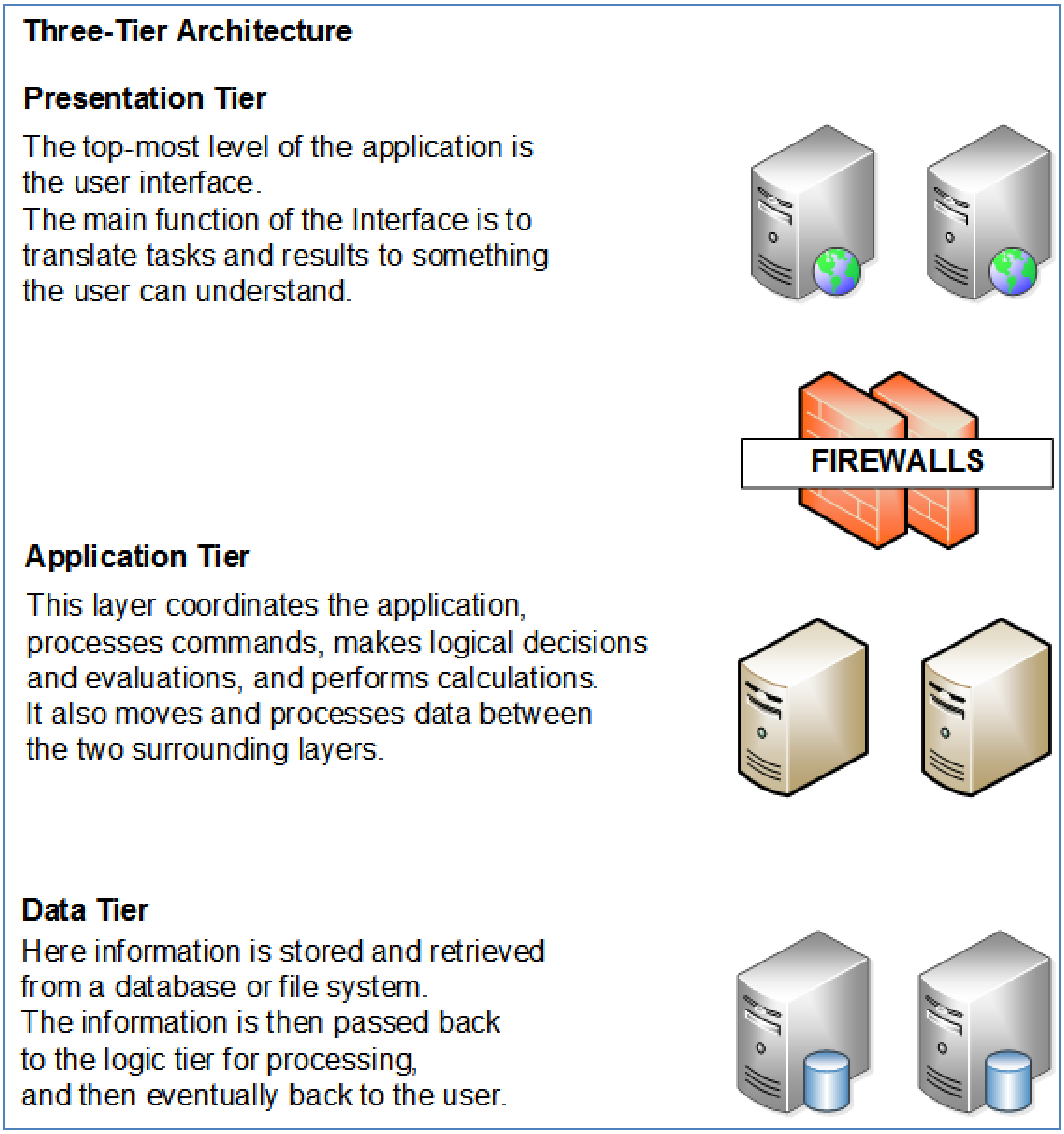
6.1.3 Infrastructure Topology

DERMS is a 3-tier solution using a client/server computing model. With three tiers or parts, each part provides separation of concerns with each tier being responsible for a particular logical function of the architecture. The most common 3-Tier Environment is a Presentation (WEB), Application (MID), Data (Database) model and this is the form that DERMS is taking.

These tiers can be applied in a traditional on premise configuration or hosted systems in a cloud environment.

ID	Tier	Components
T.1	Web	Web Server Farm – components such as the DER Commercial Platform and web services interfaces.
T.2	Application	Application Servers – components such as the DERMS Load Flow, Forecasting, and Control.
T.3	Database	Database Servers

Table 3 – Three-Tier Definition



Three-Tier Architecture

Presentation Tier

The top-most level of the application is the user interface.
The main function of the Interface is to translate tasks and results to something the user can understand.

Application Tier

This layer coordinates the application, processes commands, makes logical decisions and evaluations, and performs calculations.
It also moves and processes data between the two surrounding layers.

Data Tier

Here information is stored and retrieved from a database or file system.
The information is then passed back to the logic tier for processing, and then eventually back to the user.

Figure 5 – Three-Tier Architecture

6.1.4 Technology Architecture Components

The following diagrams illustrate configurations of the 3-tier architecture to provide separation of concerns, and high availability for DERMS. Each tier is illustrated on both an ‘Active/Active’ scenario, and an ‘Active/Passive’ scenario

- **Active/Active** – The tier is duplicated in both physical or cloud locations, and the primary location is processing and synchronising data with the secondary location. Load is always directed to the primary location, but in the event of failure, load is immediately directed to the secondary location which is running and can pick up processing instantly.
- **Active/Passive** - The tier is duplicated in both physical or cloud locations, however only the primary location is processing. Data is being synchronised with the secondary location. Load is always directed to the primary location, but in the event of failure, the secondary location is brought into service and load directed to it. There may be a delay whilst the secondary location is brought into service.

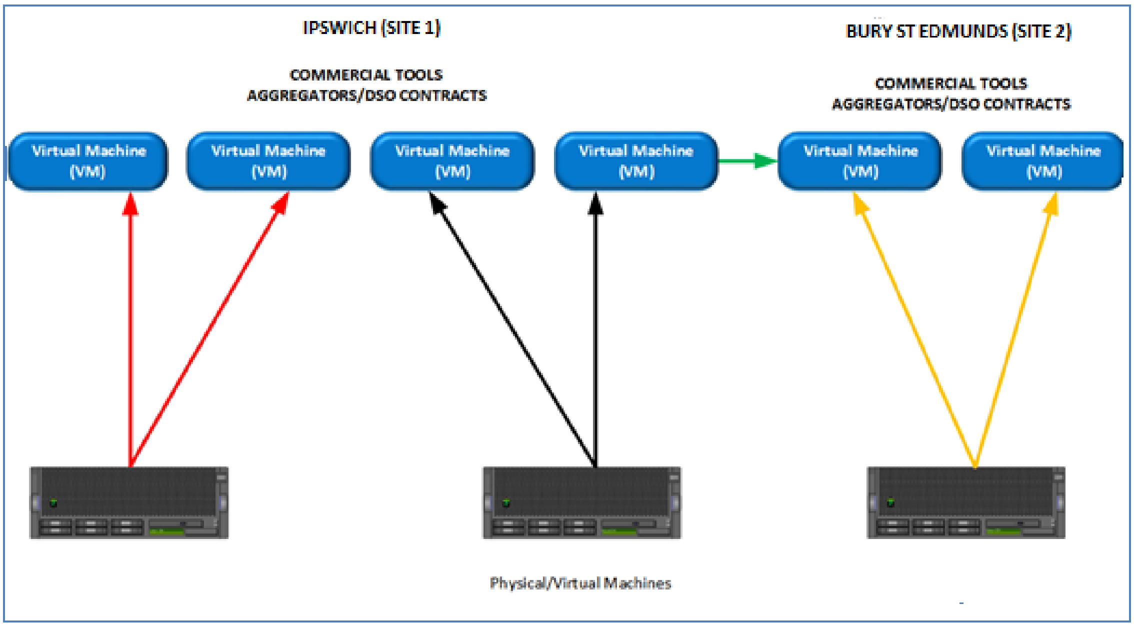


Figure 6 - Tier 1 Active/Passive Configuration

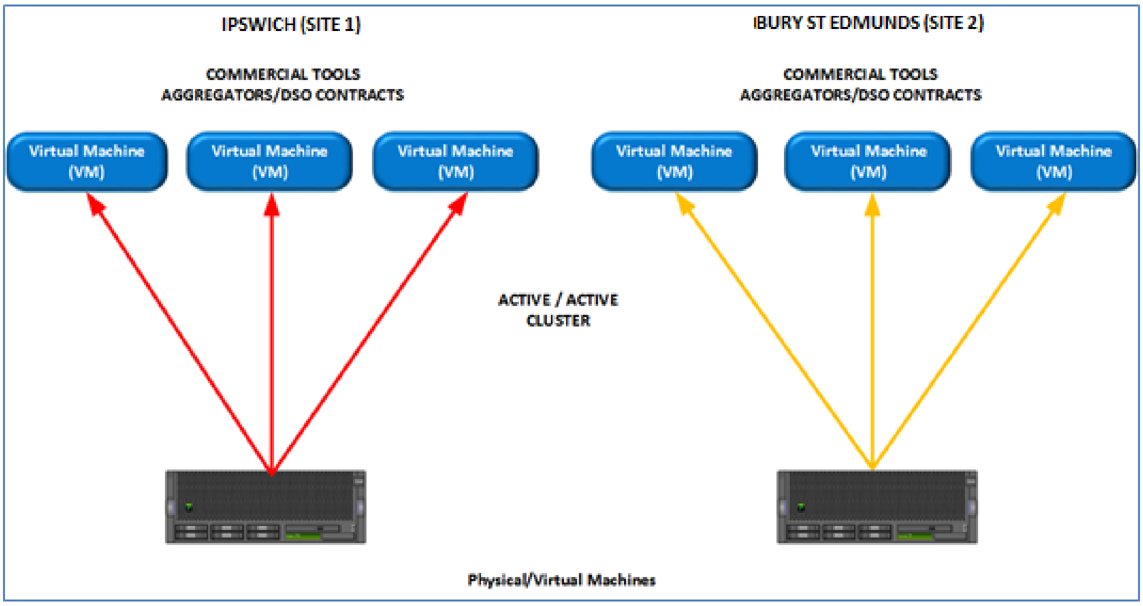


Figure 7 - Tier 1 Active/Active Configuration

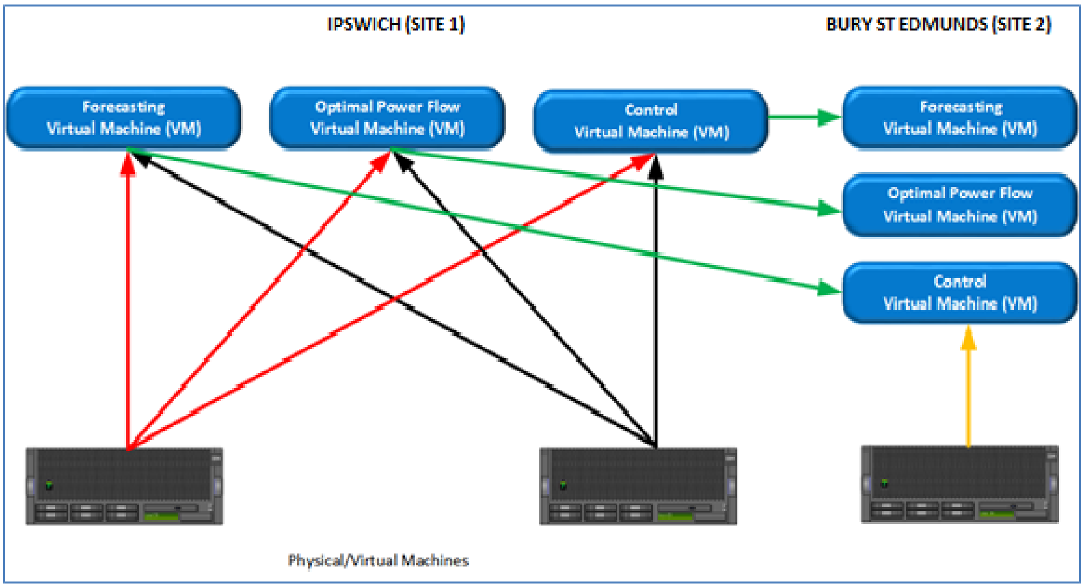


Figure 8 - Tier 2 Active/Passive Configuration

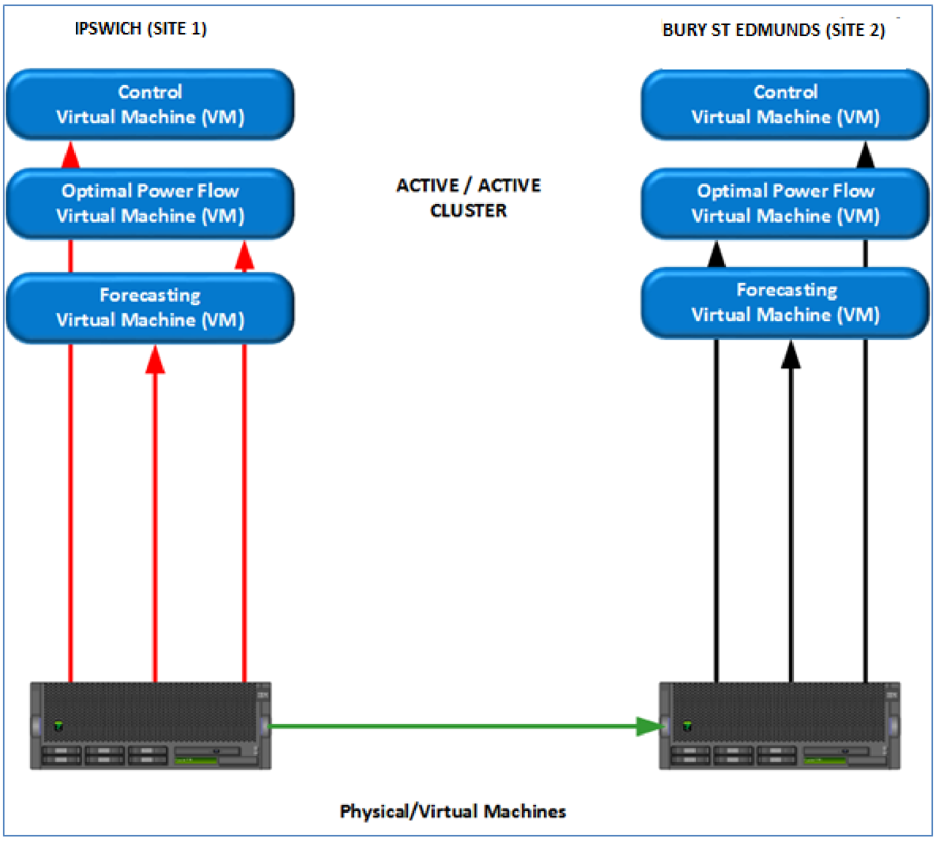


Figure 9 - Tier 2 Active/Active Configuration

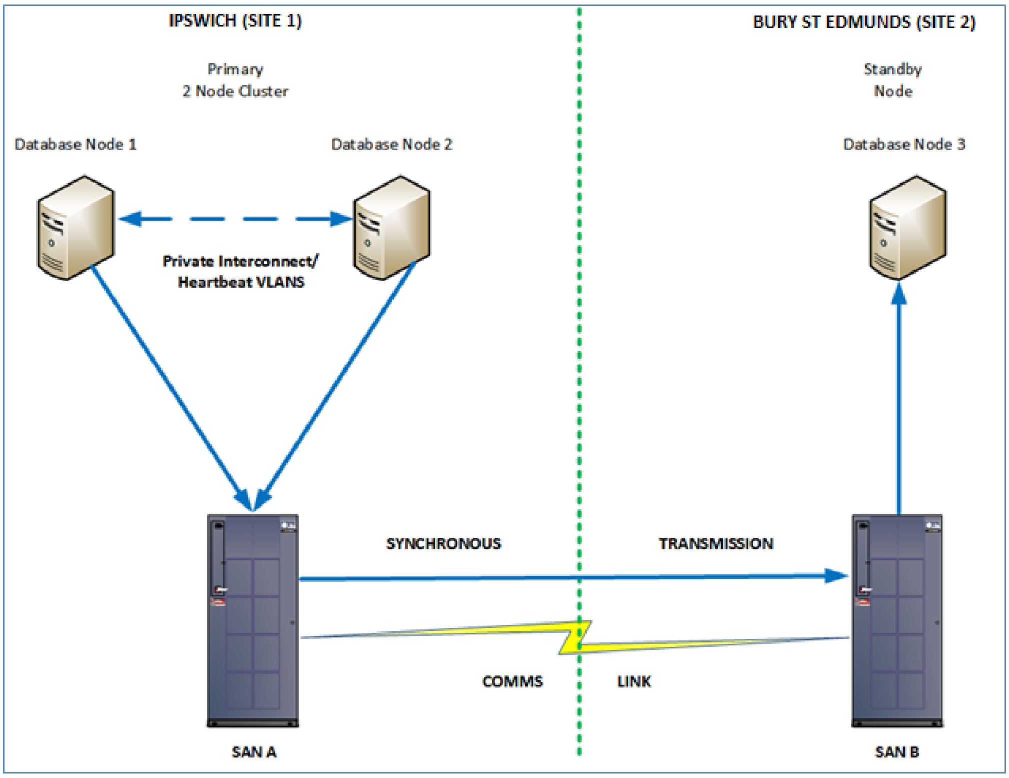


Figure 10 - Tier 3 Active/Passive Configuration

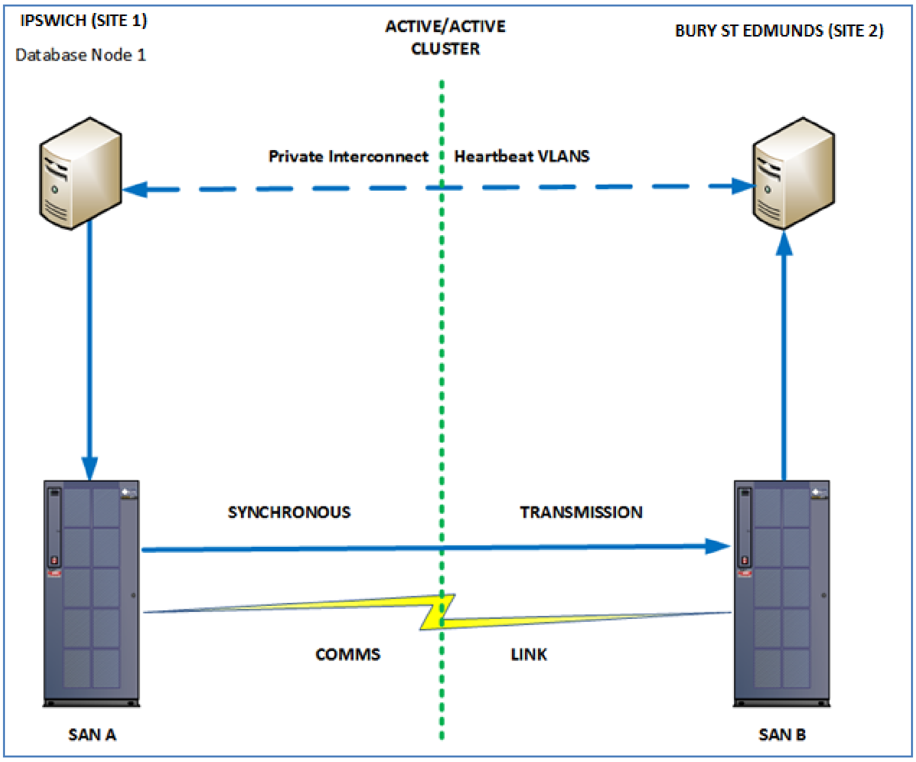


Figure 11 - Tier 3 Active/Active Configuration

6.1.5 Cloud Services Architecture

Some components of the DERMS solution may be hosted on Microsoft’s Azure cloud platform as an alternative to, or an extension of, UK Power Networks’s on premise data centres. Azure provides a range of cloud services, including those for compute, analytics, storage and networking. Users can pick and choose from these services to develop and scale new applications, or run existing applications, in the public cloud. In detailed design, each component in the solution will be evaluated to determine if it is suitable for cloud hosting, and if cloud hosting brings measurable benefits in terms of performance, scalability and cost. For example, components with the Distributed Energy Resource Management system, such as the Load Flow Engine or Contingency Analysis Engine would directly benefit from the ease of scalability that hosting in a cloud platform brings. As load increases on these components, cloud platform can automatically bring online additional computing resources on demand to cater for the additional load.

6.1.6 Infrastructure Resilience

The table below (Table 4 – Infrastructure Resilience) describes the elements of the solution that will be elaborated in detailed design to ensure the infrastructure hosting DERMS meets the resiliency requirements of UK Power Networks.

Infrastructure	Description
Load Balancers	There will be load balancers to increase capacity (concurrent users) and reliability of applications. They improve the overall performance of applications by decreasing the burden on servers associated with managing and maintaining application and network sessions, as well as by performing application-specific tasks.
Web Tier	There will be a number of web servers working as a farm which will provide resilience should any node fail.
Application Tier	Application servers will be configured in a clustered server architecture with built in server resilience
Database Tier	The database servers will be deployed on clustered server architecture for the Production Databases.
Data Centre Racking	The Production clustered nodes will be in separate racks in the DC or equivalent cloud facility. If cloud facilities are used, then this will be provide by the cloud platform.
Power Distribution	Each rack should have dual power feeds from a separate Power Distribution Unit (PDU). If cloud facilities are used, then this will be provide by the cloud platform.
Server Power	Each physical server should have dual power feeds from a separate Power Distribution Unit (PDU). If cloud facilities are used, then this will be provide by the cloud platform.
Server Network Interface Cards	Each physical server should have dual Network interface Cards for the Production and Backup VLANS. Each Interface should be on separate switches where possible. If cloud facilities are used, then this will be provide by the cloud platform.
Server Fibre Channel Cards	Each physical server should have dual Fibre Cards (FC) where required. Each FC Card should be attached to a separate SAN Fabric Switch. If cloud facilities are used, then this will be provide by the cloud platform.
Server Operation System Disks	Each physical server should have dual internal Mirrored Disks for the Operating System in a RAID 0+1 (Redundant Array of Independent Disks) configuration. If cloud facilities are used, then this will be

	provide by the cloud platform.
External Storage	External Storage Area Network (SAN) disks should be configured in a RAID 5 configuration. If cloud facilities are used, then this will be provide by the cloud platform.

Table 4 – Infrastructure Resilience

6.1.7 Data Synchronisation & Replication

The data synchronisation products will facilitate the data replication between the Primary Data Centre (Main) and Secondary Data Centre (Standby) for the databases where changes are made to the secondary SAN (Standby) which are transferred at defined intervals. This will be done either by a Storage Area Network (SAN) or Internet Protocol (IP) network. Raw Device Mappings (RDM) to SAN storage will not be required.

Although the remote copy of the data will never be as current as the primary copy, this method can replicate data over considerable distances and with reduced bandwidth requirements and minimal impact on host performance.

6.1.8 Availability & Recovery

In order to keep the secondary environment up to date at Web, Application, and Database tiers any software changes / upgrades made to production will be replicated to the DR as part of a change and release management cycle.

A DNS change from primary to secondary will be required in the event of disaster however this can be completed which will meet the RTO and RPO. There may be some manual intervention for the failover with the applications. DNS cannot be failed over automatically.

In the event of a DR invocation at Primary Data Centre the whole Environment will need to be recovered at the Secondary Data Centre, i.e. WEB, Application, and Database Tiers.

In addition to the standard Data Centre Recovery Microsoft's Azure can also be used for data backup and disaster recovery.

6.1.9 Backup and Recovery

Snapshot backups may be used to back up and restore primary and critical data. Snapshots permit faster backup and offer fast recovery time objectives (RTOs) and recovery point objectives (RPOs).

BCV is a term which stands for Business Continuance Volume. The basic idea behind it is a third mirror. That being said, people do use BCV for backup purposes. You can put all the table spaces into backup mode, then split the BCV, this is a very short process taking only a few minutes.

Tape backup is the practice of periodically copying data from a primary storage device to a tape cartridge so the data can be recovered if there is a hard disk crash or failure. Tape backups can be done manually or be programmed to happen automatically with appropriate software.

Offsite tape vaulting ensures first-class disaster protection processes for your business with minimal effort. Physical movements, barcode tracking and detailed audit trails are taken care of for you. Storing your backup media offsite increases data security, enforces appropriate retention and improves environmental protection.

6.1.10 Infrastructure Monitoring

Monitoring should be provided for applications and services. Security, data handling, transaction support, network, load balancing, and the management of the distributed systems. The deployment of these will depend on the condition of the servers.

ID	Description
MO.1	Uptime and performance statistics servers
MO.2	Applications supported by servers
MO.3	Performance and user experience of web pages, as supported by web server
MO.4	End-user connections to the server
MO.5	Measurements of load, traffic, and utilisation
MO.6	A log of HTTP and HTTPS sessions and transactions
MO.7	The condition of server hardware
MO.8	Virtual Machines (VMs) and host machines running the web server

Table 5 – Infrastructure Monitoring

6.1.11 Performance

All applications, OS Software, Systems Hardware, Networks, and SAN's should perform to an agreed specification.

6.1.12 Scalability

Each tier can be scaled horizontally by adding additional nodes. Vertical scaling can be achieved by increasing the hardware resource allocation of memory and high performance CPU if required.

6.1.13 Supportability

The support model for the Production Critical Systems should be 24/7 and 365 days a year for the applications, Operating Systems, Virtualisation and Hardware Platforms.

The key to understanding the supportability is as follows:

- Unsupported: Technology that is no longer supported or approved with the Vendor should be decommissioned. No existing or new solutions/equipment should deploy this Technology
- Current: Technology that is currently approved with the Vendor and should be deployed for new solutions, replacement of existing solutions or expansion of existing solutions
- Future: Technology that the Vendor need to assess for future deployments

7. Security Architecture

To be defined, alongside the vendor during detailed design which will come after the SDRC 9.1 phase. The considerations in this high level design are summarised in this section.

7.1.1 Security Architecture Risk Assessment

An Information Security Risk Assessment and Management of Information assets will assist in protection from external and internal threats. This requires security controls to be put in place to ensure the Confidentiality, Integrity and Availability of information assets.

The DERMS solution must comply with information security guidelines, standards and policies, such as ISO27001, the Good Practice Guides and more specifically the following policies:

- Access Control Policy;
- Password Policy;
- Remote Working Policy; and
- Data Protection Policy

As part of the security risk assessment of the DERMS solution the various risks will be identified. Risk mitigation and Control measures will be proposed for all risks classed as Medium or High, while those identified as low risk are considered for no action.

7.1.2 Physical Security

Physical security assessments and measurements ensure that information assets and information processing facilities are protected from unauthorised physical access, damage and interference.

7.1.2.1 Physical entry controls

This will require that secure areas are protected by appropriate entry controls to ensure that only authorised personnel are allowed access.

7.1.3 Equipment Security

The purpose of equipment security is to prevent the loss, damage, theft or compromise of assets and interruption to the organisation’s operations.

7.1.3.1 Unattended user equipment

To prevent unauthorized use of user equipment:

- All user PCs and workstations will be configured to automatically lock after a preconfigured period of time to prevent unauthorised use and require a password to unlock;
- The system will require that the Identification and Authentication Process is repeated to unlock the device before work can be continued;
- A warning screen, which is displayed prior to log-on at PCs and workstations will warn the reader that unauthorised access to systems will result in disciplinary or legal action being taken;
- Users will be instructed to ensure any portable equipment, PC or workstation is secure by:
  - Making sure they log-off before leaving any portable equipment; and

- Manually locking it if unattended for extended periods e.g. Kensington locks on laptops, or by locking away when not in use.

7.1.3.2 Mobile computing

For remote working off-site, users will follow UK Power Networks' Remote Working Policy, which includes:

- Specifications for the protection of data at rest on personal electronic devices (PED) using validated cryptographic controls i.e. whole disk encryption;
- A registration scheme to allow for audit and accountability of any PEDs;
- Procedures to establish, implement, review and maintain the PED configuration and security baseline commensurate with UK Power Networks requirements;
- Operating procedures and instructions for both remote working users and remote access solution administrators that clearly state:
  - what remote working practices are and are not authorised;
  - user responsibilities and controls that rely on user participation;
  - the prohibition of the use of personally-owned PEDs for business purposes (or from being brought into business premises);
  - the prohibition of the use of business owned PEDs for personal use; and
  - the prohibition of taking PEDs overseas.
- User training and awareness;
- Procedures for recording and managing incidents and contingency plans for managing any potential compromise; and
- Authorisation and controls for the import and export of PEDs from official premises.

7.1.4 Network Security

Network security aims to ensure the protection of information in networks and its supporting information processing facilities.

7.1.4.1 Network Controls

This requires the management and control of networks to protect information in the systems and applications. This involves the control of communication for the transfer of information containing costs and supply between:

- UK Power Networks and National Grid (Grid Supply Points);
  - DERMS and National Grid Control communicate through ICCP link
  - The ICCP link goes through a different tier of firewalls and DMZ
  - ICCP protocol is inspected using the application based rules that only allow certain controls and connections
- UK Power Networks and Distributed Energy Resources (DERs);
  - Appropriate network controls will be required to be implemented at the substation end, locally, for the DER for when they make a connection to UK Power Networks
- UK Power Networks internal systems; and

  - DERMS and Existing Systems will operate in separate zones as part of the zone segmentation to keep them in separate areas of the network
- WAN connections.

To ensure security controls are in place, the use of encrypted and authenticated network services and protocols where required for both user and system to system communications, including:

- HTTPS instead of HTTP;
- SFTP or SCP instead of FTP; and
- SSH for terminal sessions.

7.1.4.2 Security of network services

The network services agreements will ensure that security mechanisms, service levels and management requirements of all network services are identified and included, whether these are provided in-house or outsourced.

7.1.4.3 Network Segregation

Conceptually a network security zone is defined as an area occupied by a group of systems and components with similar security requirements for the protection of information and the attendant characteristics associated with those requirements including:

- Data confidentiality and integrity requirements;
- Access controls; and
- Audit, logging, and monitoring requirements.

Security zones provide containment of security threats through component (user, application, network and system) segmentation.

The network will be segmented into sub zones such as Commercial, National Grid Control, Met Office, Existing Systems, Operational, Enterprise Application and DER zones.

The network segmentation will be set up with firewalls, IPS and web application firewalls to ensure there are DMZs built into the design to prevent unauthorised access to different areas of the network. There will be a need to separate the corporate network and SCADA network to prevent unauthorised access and use of the SCADA network.

For the station RTUs they have their own DMZ and communicate on a private network using APNs, DSL and satellite. There will be the requirement to upgrade any legacy RTUs to prevent security breaches.

7.1.5 Access Controls

All service access to information will be controlled and be based on the 'need to know' principle and on a 'least privilege' basis. Control of access to systems and data will be in accordance with UK Power Networks' Access Control policy.

The Access Control Policies and associated Security Procedures will specify:

- A clear definition of responsibilities for all authorised users;
- Roles and responsibilities for all types of system usage;
- Control of access:
  - To all systems components;

    - To all data within the systems;
    - To all stored information and documentation;
    - To database facilities and tools;
    - To applications running on servers and workstations; and
    - To the network and network management systems.
- For exceptional deletion of data when authorised;
- Procedures for allocation of access rights to IT systems and for temporary elevation of privileges;
- Management, assignment and revocation of privileges;
- Identification and authentication of human and system "users"; and
- Password management, including methods for security passwords storage which cannot be compromised (i.e. not generic Word docs) and both password generation and expiry.

Accountability of individuals is essential and segregation of duties is enforced where appropriate.

7.1.5.1 User access management

The provision of user access for UK Power Networks' data will be managed and controlled at various levels for authentication and authorisation:

- Access to systems will be through dual authentication with local certificates on the UK Power Networks' devices to confirm these are valid UK Power Networks' equipment;
- User registration will be managed and controlled by UK Power Networks, including:
    - Responsibility for registering, granting user access level and revoking user access
    - Being accountable for ensuring formal procedures are in place to control this, and that these procedures are followed
    - Divide user and device privileges between exclusive 'administrator' and 'view only' user profiles
- Review of user access rights periodically
    - Including revalidation of user access rights and privileges granted to users
    - Records of these reviews will be maintained

7.1.5.2 User password management

For UK Power Networks' applications, UK Power Networks will have responsibility for:

- The issue of user passwords; and
- Accountability for ensuring formal procedures are in place to control this (including that appropriate rules are in place for passwords), and that these procedures are followed.

Enforcing Password Policies that will require passwords to:

- Remain private to the user;
- Be customised by specifying minimum password length, as well as usage of lower case, upper case, numeric and special character:

    - Be of sufficient length so that they are difficult to guess or calculate by manual or automated means, including the use of decryption tools.
- Will be stored securely in a one-way encrypted form;
- Change passwords:
    - That are subject to any possible compromise or suspected security breach;
    - Regularly to be within their life span before reaching their expiry (preference is for at least every six months, unless a more frequent change is required by the system or service); and
    - Temporarily assigned by the IT administrator immediately on first use.

UK Power Networks will provide security awareness training, to guide their users on how to follow good security practice in the selection, use and storage of passwords.

7.1.5.3 Third Party Remote User Access

Third party remote user access to components of the Technical Solution shall only be possible where explicitly specified and controlled or authorised by UK Power Networks. Where third party remote access is specified, access to remote users shall be provided via UK Power Networks' VPN access facilities.

A limit will be enforced for the number of connections allowed to create remote sessions (i.e. via terminal services) to a minimum required amount.

7.1.6 Application Authentication/Authorisations

The following access control requirements will be implemented to prevent unauthorised access to systems and applications:

- Development of Access Control Policy to restrict access to information and application system functions;
- Secure log-on procedure;
- Password management system to ensure quality passwords; and
- Privilege utility programs to ensure the capability of overriding the system and application controls is restricted and controlled.

7.1.7 Data Security

7.1.7.1 Data

The data required to be secured includes personal, intellectual property and commercial data, such as:

- Weather forecast data from Met Office;
- Historic load data;
- DER data containing commercial availability and capability from each DER is sent to the ICT solution where data of amount of MW/MVars and costs of each market participant is gathered;
- Other non-participating DER information;
- Service availability at the interface between UK Power Networks and National Grid called the Grid Supply Point (GSP) includes:

    - Simulation of possible faults in the network and their consequences to ensure that the services provided will not be detrimental to the distribution network
- MW and MVar service availability and costs of DERs presented to National Grid.

The changes of global legislative, government and industry regulatory requirements and their impact on the Data Privacy and Data Protection Policies needs to be considered and as a minimum UK Power Networks will:

- Collect, process, store and transfer Personal Information in compliance with applicable laws and regulations;
- Classify Personal Information as Sensitive Information;
- Require its employees and contractors to abide by their confidentiality obligations;
- Employ physical, electronic, logical and organizational safeguards and procedures designed to protect the confidentiality, security, and integrity of Personal Information; and
- Process requests for disclosure of information in accordance with client contract requirements and applicable laws.

Access to information will be controlled and based on the role of a person such that:

- Network protection, monitoring and reporting will be part of the standard UK Power Networks’ operation environment;
- Anti-virus software is deployed on all our equipment and updates are automated;
- Operating System updates are also maintained to manufacturer levels;
- All critical data is backed up and stored in appropriate locations;
- Authentication and authorization are based on the corporate Identity Management System;
- Depending upon the confidentiality level we will apply standard authentication (password), strong authentication (token) or PKI to identify devices; and
- The network will be segmented into sub zones such as Commercial, National Grid Control, Met Office, Operational Enterprise Applications and DER zones.

7.1.7.2 Protection of organisational records

Records stored electronically will be accessible throughout the required retention period and will be safeguarded against loss due to future technology change.

Data will be retrievable to comply with legal requirements as requested by a court of law, e.g. records required can be retrieved in an acceptable timeframe and in an acceptable format.

UK Power Networks will comply with all national Data Protection legislation, in governing the handling of all personally-identifiable data held on or processed by the systems it operates. "Personal data" is defined as data that refers to any living individual.

The principles of Data Protection legislation require that UK Power Networks, as the service data processor, will:

- Take measures so that processing is only performed by authorised persons, who will be subject to appropriate clearance and vetting;
- Achieve and maintain compliance through guidance and training;
- Provide guarantees and assurance to the data user;

- Act only within the contract with the data user;
- Disclose data only with the data user's consent; and
- Keep data securely.

UK Power Networks will make its staff aware of the consequences of the misuse of information processing facilities through user training, user awareness, and, by implementing a protective monitoring policy and informing users of its existence.

Computer Misuse legislation recognises three criminal offences regarding unsanctioned access to data held on computer systems. It does not excuse computer users from taking all reasonable precautions to prevent an attack in the first place. The offences are:

- Unauthorised access which covers simple hacking;
- Unauthorised access with criminal intent i.e., to assist with the perpetration of a more serious crime, such as fraud or blackmail; and
- Unauthorised amendment or damage to data which covers, amongst other things, the introduction of viruses.

7.1.8 Security Events and Monitoring

UK Power Networks have a 24x7 SOC service run by Symantec who provide a triage system for reporting any security incident events.

Security events are logged and will include user login, logout, and change of parameters, configurations, or updates of firmware. For each event date and time, user, event ID, outcome and source of event are to be logged. Access to the resulting log audit trail will be available to authorised users only. These logs are kept for the period of a year.

System audit tools (programs and log files) will only be available to authorised personnel and will be protected to prevent any possible misuse or compromise.

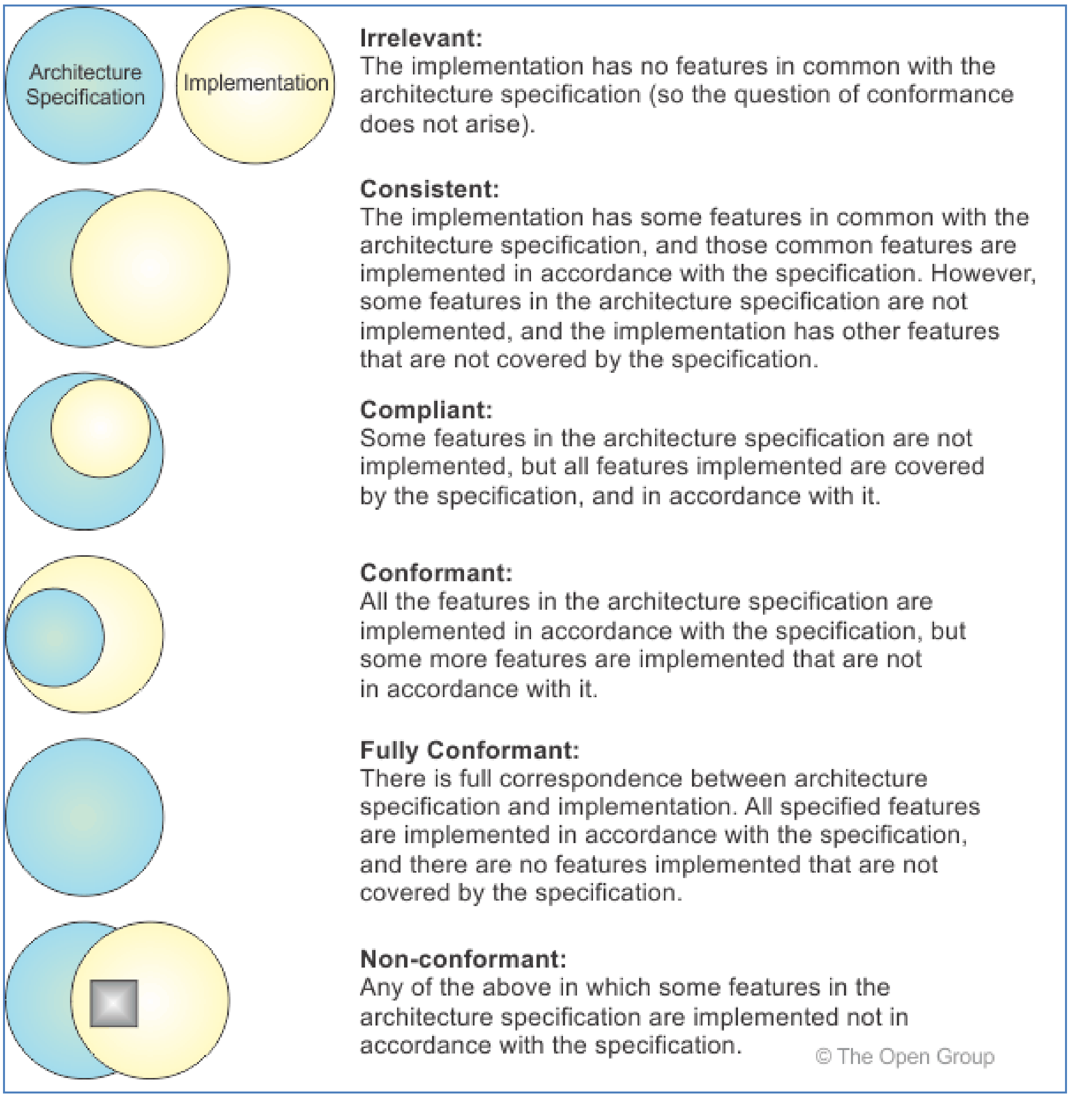
7.1.9 Compliance with legal requirements

Within the UK, the following legislation will be applicable:

- The Data Protection Act 1998 - structured or defined records relating to living individuals will be stored or processed by the service. There is a reform of data protection legislation, GDPR, which will need to be considered, since this reform of data protection legislation is due to replace the Data Protection Act 1998 from May 2018;
- Computer Misuse Act 1990 - all users with access to the system will be subject to the Computer Misuse Act;
- Freedom of Information Act 2000 - it is envisaged that information may be subject to the Freedom of Information Act;
- Environmental Information Regulations 2004 – facilities may be subject to information requests under the Environmental Information Regulations Act;
- Copyright (Computer Programs) Regulations - the appropriate licences for system operation will be procured and validated; and
- Civil Evidence Act 1968 and PACE Act 1984 - there is the possibility that the system audit log records may be used in support of investigations regarding misuse of the service.

8. Architecture Compliance Checklist

The architecture compliance checklist provides an indication of how compliant the architecture is based on the TOGAF[2] model as follows.



Irrelevant:
The implementation has no features in common with the architecture specification (so the question of conformance does not arise).

Consistent:
The implementation has some features in common with the architecture specification, and those common features are implemented in accordance with the specification. However, some features in the architecture specification are not implemented, and the implementation has other features that are not covered by the specification.

Compliant:
Some features in the architecture specification are not implemented, but all features implemented are covered by the specification, and in accordance with it.

Conformant:
All the features in the architecture specification are implemented in accordance with the specification, but some more features are implemented that are not in accordance with it.

Fully Conformant:
There is full correspondence between architecture specification and implementation. All specified features are implemented in accordance with the specification, and there are no features implemented that are not covered by the specification.

Non-conformant:
Any of the above in which some features in the architecture specification are implemented not in accordance with the specification.

Figure 12 Architecture Compliance model[3]

One the detail design phase is completed, each of the architectural principles listed in Table 6 will be assessed against the TOGAF architecture compliance model.

Principle	Statement	Compliance Note
Information is accessible	Information is accessible in a timely manner for users to perform their business functions.	

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[2] The Open Group Architecture Framework (TOGAF) is a framework for enterprise architecture which provides a comprehensive approach for designing, planning, implementing, and governing an enterprise information architecture.

[3] http://pubs.opengroup.org/architecture/togaf9-doc/arch/chap48.html

Information is defined	Information is defined consistently throughout the enterprise and the definitions are understandable and available to all users.	
Decisions are based on a cost/benefit analysis	Decisions are based on an analysis of the requirements and the matching of the solution to the delivered benefits.	
Re-use before buy before build	Using applications and infrastructure that is already in use is preferred. Where this isn't appropriate buying standard components is preferred over developing custom development.	
Information Systems are implemented cost effectively	The implementation of information systems should take the total cost of ownership into account.	
Changes in the IT architecture do not compromise business continuity	The IT architecture supports the business and changes should be implemented in a way that does not put the business at risk	
Software and hardware should conform to defined standards that promote interoperability for data, applications, and technology.	IT components should be based on defined and agreed standards that promote interoperability and technical interoperability.	
Processes are standardized	Critical business processes are defined and standardized.	
Documents are stored in the DMS	Documents are a critical asset and should be stored in the system that is designed for their storage and management.	
Reporting and Analytical applications don't use the operational environment	Reporting from a separate non-operational environment prevents unpredictable performance from operational systems.	
Access to IT systems is authenticated and authorized	People should not have access to information which they are not authorized for.	
Information is organized	The use of information is critical to the operation of the business and it should be organised.	

Table 6 - Architecture Compliance List

Transmission & Distribution Interface 2.0 (TDI 2.0)

Working together for a sustainable energy future